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A LEVEL OF REPAIR MODEL
FOR THE INDONESIAN NAVY

by

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A Level of Repair Model for The Indonesian Navy

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I. INTRODUCTION

A. BACKGROUND

The rapid advances in technology which have occurred since the end of World War II have led to the design of systems of increasing complexity. As a consequence the problem of maintenance support is also becoming more complicated and difficult to perform. Increased complexity of system design appears to be inevitable as new missions are defined and as higher performance requirements are specified.

Considerable resources have been expended on research on improving system reliability. Reliability directly influences the need for preventive maintenance and repair. The achievement of increased reliability may simultaneously require an increased demand on the maintenance technician in terms of skill, training, and maintenance man-hours, and on the logistics pipeline in terms of spares or repair parts. The consequence is increasing logistic support cost.

During the last decade costs associated with system/product acquisition and logistic support have increased at an alarming rate. At the same time decreasing government budgets combined with inflationary trends have resulted in less money being available for procurement of new systems and for the maintenance and support of those systems already in use. This requirement to increase overall productivity in a resource-constrained environment has forced attention to all aspects of a system's life-cycle. The system's life-cycle costs must be given more attention, particularly those costs associated with system operation and support since these costs often constitute a major portion of the total life-cycle costs.

In the U.S. Navy weapon systems are evaluated from the support point-of-view from their conception. The sources of high support costs are addressed as part of design. The goal is to minimize maintenance costs without sacrificing system operational effectiveness.

The Indonesian Navy, like other navies of developing countries, is not involved in design development. Instead, it uses systems developed by major countries like the United States. With such systems comes the need for maintenance. How best to perform this maintenance is the problem. Since a significant portion of the Indonesian Navy's budget goes to support such weapon systems, improvement in logistic support management of such systems by the Indonesian Navy is considered to be very important.

B. OBJECTIVE OF THE THESIS

The purpose of this thesis is to develop a methodology for making level of repair (LOR) decisions for new weapon systems which have been developed by other countries and are going to be purchased from them by the Indonesian Navy. The objective of this methodology is to allow the existing maintenance organization of the Indonesian Navy to accomplish the required maintenance at least cost.

C. SCOPE OF THE THESIS

The current application of LOR decisions by the U.S. Navy will be studied to structure a specific model of repair analysis that can be applied in the Indonesian Navy's existing organization.

D. METHODOLOGY

The methodology developed in this thesis will be predominantly an extension of the LOR analysis currently in the literature. A comparison of the planning for

logistics by the Indonesian Navy with that of the U.S. Navy will be needed as the first part of model development.

E. RESEARCH QUESTIONS

The author seeks answers to the following research questions:

1. How can LOR models be used for weapon systems that have already been designed?

2. How can the LOR decisions incorporate the existing maintenance organization of the Indonesian Navy?

3. Is there any possibility that the least total maintenance costs can be achieved with LOR analysis on existing weapon systems?

4. What cost analysis model structure will ensure the least total life-cycle maintenance cost?

5. What are the problems, if any, with applying this limited LOR analysis to the weapon systems being purchased for the Indonesiar Navy?

F. LIMITATIONS AND ASSUMPTIONS

Unfortunately, a major factor that limited the research effort was the scarcity of Indonesian Navy data. This scarcity is caused by the weak communications link between the United States and Indonesia. In addition, the author experienced restrictions on access to certain U.S. documents because of their security classification. These constraints might affect the validity of the analysis.

The following assumptions are used in the analysis to follow:

1. No changes have occurred in the policy of the Indonesian Navy associated with logistic support management during the period from 1987 to 1989. Thus, the knowledge of the author, gained prior to 1987, is assumed to be correct.

2. The equipment to be analyzed in the example is a simplified configuration of a typical component of an existing weapon system.

G. PREVIEW OF THESIS

In Chapter II the author traces the evolution of the Indonesian Navy since World War II to provide insight about the management, policies and planning for logistics used by the Indonesian Navy. Chapter III then introduces the reader to the concepts of system life-cycle, system effectiveness, life-cycle costs and cost effectiveness analyses.

Chapter IV proposes a model for LOR analysis which incorporates the existing maintenance organization of the Indonesian Navy. A procedure for determining the lowest life-support cost alternative is also described.

Chapter V describes an example application of the model developed in Chapter IV. The details of the computations of the life-support costs for the alternative maintenance levels are described.

Chapter VI presents a summary of the thesis, and its conclusions and recommendations.

II. INDONESIAN NAVY'S LOGISTIC MANAGEMENT REVIEW

A. THE DEVELOPMENT OF MAJOR WEAPON SYSTEMS

The evolution of major weapon systems in the Indonesian Navy since World War II will be reviewed to provide insight into the general structure of the organizations responsible for the logistic support management of such systems. This evolution will be divided into three periods corresponding to the major changes in the management effort.

1. The First Period (1950-1960)

The first period was during and immediately after the Indonesian War of Independence. The Indonesian Navy began its ship acquisition by transferring some ships from the Federal Schepedienst, Netherlands East Indies [Ref. 1:p. 24].

After the War of Independence, the Indonesian Navy expanded its fleet with acquisitions from Italy, U.S.A., U.S.S.R., West Germany, Yugoslavia, and Japan. During this period, the Indonesian Navy bought frigates, corvettes, and submarines for the first time. The first submarines were purchased from Poland and transferred to the Indonesian Navy in August 1959.

Under the Mutual Defense Assistance Program, the Indonesian Navy bought submarine-chasers and landing ship transports from the United States. Under the government of the Netherlands East Indies, the shipyards DROOGDOK MAATSCHAPPIJ, Jakarta, and DROOGDOK MAATSCHAPPIJ, Surabaya, produced three auxiliary minesweepers (175 tons) and finished another auxiliary

minesweeper of the same type which was started during the Japanese occupation [Ref. 2:p. 63]. These ships were the result of Dutch shipbuilding technology.

During this period, maintenance activities were designed to meet the operational requirements without any major distinction between the levels of maintenance. These maintenance activities were a consequence of very limited budgets, few adequately trained personnel, limited test equipment, and poor supply support [Ref. 3:p. 29].

2. The Second Period (1961-1972)

This period witnessed the largest number of acquisitions of the weapon systems that has ever occurred in the Indonesian Navy. These acquisitions occurred in conjunction with the return of West Irian (West Papua) to the Republic of Indonesia. These acquisitions produced a number of benefits for Indonesia, including: improved defense of the long coast line, safeguarding of offshore oil installations, and transfer of technology to the Indonesian Navy. During this period the Indonesian Navy developed the ability to operate and utilize modern weapon systems and, at the same time, acquired the skill to maintain all system components. As in the first period maintenance activities were designed to meet operational requirements with no major distinctions being made between levels of maintenance. During this period almost all corrective maintenance actions were effectively performed for the first time because all ships' crews had received at least one year of training in such maintenance actions in the U.S.S.R.

Following the period from 1965 to April of 1967, during which all Indonesian military procurements were suspended, a new government was formed. During this second period the Indonesian Navy purchased no ships from the United States until after April 1967. The new Indonesian government requested that the United States help develop the Indonesian Armed Forces [Ref. 2:p. 65].

3. The Third Period (1973-1989)

During this period the Indonesian government, headed by President Suharto, rebuilt the Indonesian Armed Forces. Because some of the equipment and ships acquired from the U.S.S.R. were inoperable, and spares and replacement parts were unavailable, many of them had to be scrapped.

At the beginning of this period, the Indonesian Navy bought four used frigates, of the former U.S. "CLAUDE JONES" class, which were commissioned in 1973 and 1974. At the same time the Indonesian Navy ordered several U.S. designed patrol boats from Korea. In 1975 it bought three new corvettes from the Netherlands (commissioned in 1979). A project management organization was formed for this acquisition and was located in Wilton Fijenoord, Shiedam, Netherlands. The Indonesian Navy task force was helped by the Royal Netherlands Navy (KONINGLIJKE MARINE).

In 1979 two submarines were purchased from West Germany through the assistance of the West German Navy (BUNDESWHER MARINE). In 1985 three frigates of the ex-BRITISH "TRIBAL" class were purchased and commissioned by the Indonesian Navy. In 1986, 1987 and 1988, three used frigates were purchased from the Netherlands and modernized [Ref. 4:pp. 255-259]. During this period a majority of the current logistics management and maintenance methods were introduced by the Dutch Navy since most of the modern ships acquired by the Indonesian Navy were purchased from the Netherlands. In addition, all of the ships' crews and base maintenance personnel received on-the-job training in the Netherlands.

In 1980 Indonesia established a 20-year strategic plan to develop a Navy of 25,000 seamen and 5,000 marines to man a fleet that would include four fast A/S frigates, six submarines, six light fast attack craft (missile, gun and torpedo), six

minelayers, six minesweepers, a fast headquarters ship, a fast supply ship, and one or two more corvettes. Additional plans in 1986 added six more submarines and three more frigates to the plan. The construction of those three frigates has begun. The acquisition of five more frigates, two submarines, four fast attack craft (missile), a new patrol craft and a new training ship has been completed. All major surface ships are also being fitted with missiles.

Indonesia now has nine shipbuilding yards (seven private and two government-owned) and is in a position to build its own ships up to frigate size. Requests for proposals have been sent to 13 industrial countries' firms for the design of 2300-2800 ton frigates (details must be submitted by the end of this year). In all, 23 ships are planned, the first two to be built in the selected designer's yard, the remainder at P.T. Pal (a private shipyard company), Surabaya, Indonesia, over the next 30 years [Ref. 4:p. 255].

B. LOGISTIC SUPPORT MANAGEMENT

In 1985 to achieve greater effectiveness and efficiency the Indonesian Navy reduced the number of its unit commands to only a few by consolidating some and liquidating others. Some of the management publications issued by the Indonesian Navy, such as management guides, regulations, and directives, as well as a logistic support management guide, have been revised to incorporate the structure and requirements of the new organization. At the beginning of 1987 the Indonesian Navy issued a new logistics management guide called "Pola Pembinaan Bidang Materil, PUM-1.03" [Ref. 5:pp. 1-30]. PUM-1.03 is a general guide for managing Naval material and logistic support. The major change is the Navy's maintenance policy that depot maintenance for Naval ships will be performed by shipyard contractors

[Ref. 5:p. 23]. The Indonesian Navy has selected six shipyards (four private and two government owned). These will be listed in the next section.

The main objective of logistic support management of the Indonesian Navy is to support the integrated weapon systems (SSAT). The SSAT (Sistim Senjata Armada Terpadu) is defined by the Indonesian Navy as the integration of four force components:

1. SHIPS

2. AIRCRAFT

3. MARINE CORPS

4. NAVAL BASES (Naval Harbors)

Since Indonesia is an archipelagic country, many Naval bases are required throughout the country. There are ten Naval bases in Indonesia at present. For this reason Naval bases are included in the four components.

The Indonesian Navy applies an integrated logistic support concept to weapon systems during the provisioning process before initiation of the program whenever possible, and throughout the life-support phase (operational-use phase). Application of integrated logistic support to only the operational-use phase is for weapon systems that have already been designed without the Indonesian Navy's involvement in the design process.

Basically, material and logistic management in the Indonesian Navy consists of eight functions [Ref. 6:pp. 25-26]:

1. Material requirement determination

2. Procurement

3. Inventory

4. Maintenance

5. Information systems

6. Material distribution

7. Disposal

8. Standardization

In the organizational structure of the Indonesian Navy, four directorates deal with logistics and material management, as illustrated in Figure 2.1 [Ref. 7:p. 56]. The four directorates are under the control of the Deputy Chief of the Naval Staff-Logistics. In addition, there are three unit commands within the organization responsible for managing the ships. These are the Eastern Fleet Command, headed by the Commander-in-Chief Eastern Fleet, located at the Naval base at Ujung, Surabaya East Java; the Western Fleet Command, headed by the Commander-in-Chief Western Fleet, located at Jakarta, West Java; and the Military Sea Lift Command, headed by the Commandant of Military Sea Lift, located at Naval base at Tanjung Priok, Jakarta. In dealing with logistic and material management, each unit command has its own organizational structure.

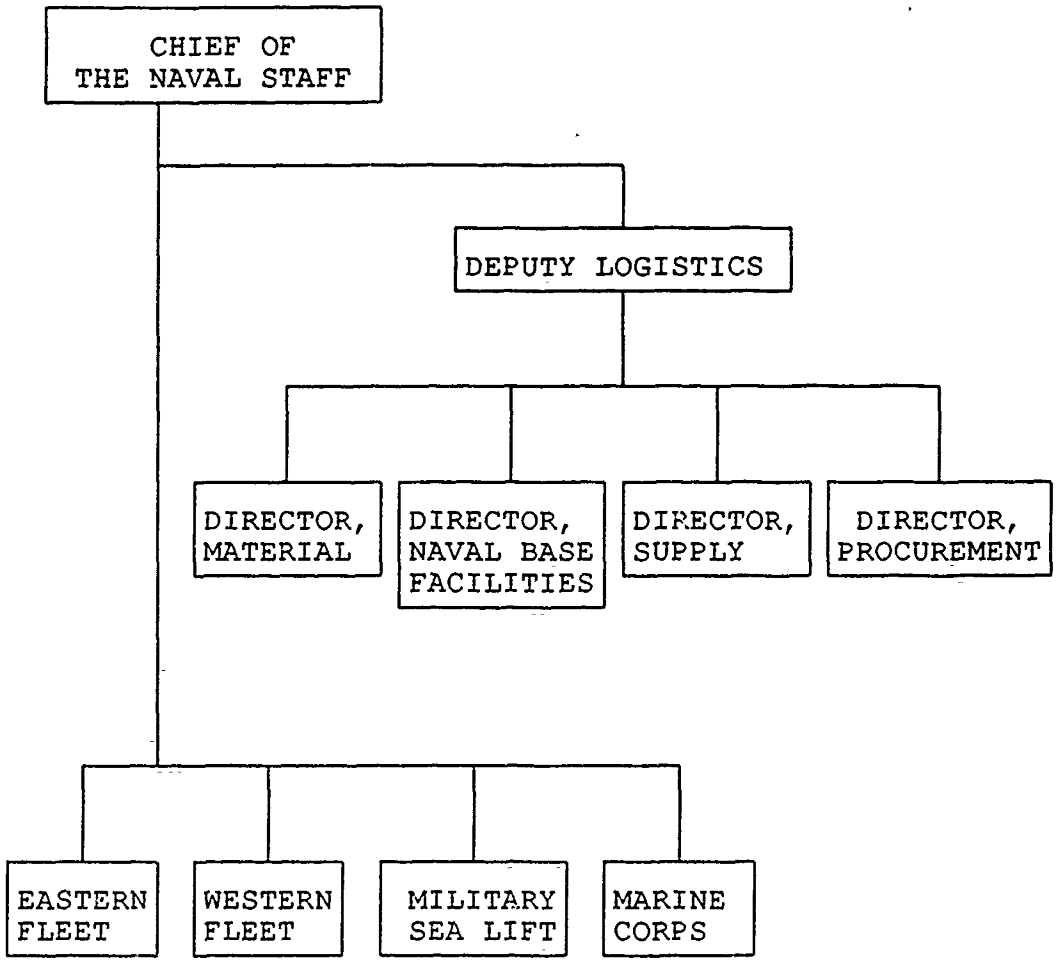


Figure 2.1: Organizational Structure of Logistics Management in the Indonesian Navy [Ref. 7:p. 56]

The development of the Western Fleet began in 1985 in conjunction with the new organization of the Indonesian Navy, and is still evolving. The Naval base for the Western Fleet, being built at Teluk Ratai, South Sumatra, is expected to be finished in the near future.

The Indonesian Navy must support both old and new ships which have been purchased from different countries. The approximate number of ships managed at

present by the three unit commands described above are listed in Table 2.1 [Ref. 4:p. 255].

Additional ships to be purchased under the present plan are one frigate, six fast attack craft (gun/torpedo), six hydrofoils, two main warfare vessels, and two mainsweepers [Ref. 4:p. 255].

C. OVERVIEW OF THE PRESENT MAINTENANCE ORGANIZATION

For preventive maintenance, maintenance management prepares a maintenance plan and schedule for each "new" ship [Ref. 3:p. 31]. This method was initiated in the third period when the Indonesian Navy began acquiring modern systems such as new ships from the Netherlands and West Germany. All weapon systems on each ship are provided with a maintenance schedule. For example, a ship's systems may have a maintenance schedule which consists of daily inspection; weekly, monthly or quarterly maintenance; and major overhauls every two years.

Each ship has been projected to accomplish a specific mission, depending on the operational requirements needed and planned [Ref. 3:p. 31]. Based on these operational requirements, the Indonesian Navy determines the maintenance plan for each ship.

Corrective maintenance activities are basically organized into three levels [Ref. 5:p. 23]:

1. Organizational maintenance, performed by the using organization;
2. Intermediate maintenance, performed by a Naval base's maintenance facility;
3. Depot maintenance, performed by the designated shipyard contractor.

TABLE 2.1: Number of Ships Managed by Three Unit Commands

TYPE	NUMBER
Patrol Submarines	2
Frigates	14
Fast Attack Craft (Missile)	4
Fast Attack Craft (Gun/Torpedo)	2
Large Patrol Craft	12
Coastal Patrol Craft	8
Hydrofoils	5
LST's	15
Amphibious Craft	62
Minesweepers	2
Survey Ships	9
Submarine Tenders	2
Replenishment Tankers	1
Harbor Tankers	5
Cable Ships	1
Tugs	6
Training Sailing Ship	1
Miscellaneous	23

At present, because of the sophistication of the systems being maintained and an inadequate number of technical personnel, the only maintenance actions performed at the organizational level are replacements [Ref. 3:p. 34].

The maintenance functions at the depot level are performed by the shipyards selected by the Indonesian Navy. The Indonesian Navy has designated six shipyards to perform depot maintenance:

1. Perusahaan Terbatas (PT) Pal Indonesia shipyard

2. Perusahaan Negara (PN) Dok Jakarta shipyard

3. Perusahaan Negara (PN) Dok Surabaya shipyard

4. Perusahaan Terbatas (PT) Pelita Bahari shipyard

5. Perusahaan Terbatas (PT) Kodja shipyard

6. Perusahaan Terbatas (PT) Intan Sengkunyit shipyard

"Perusahaan Terbatas (PT)" refers to a private company, and "Perusahaan Negara (PN)" refers to a government owned shipyard.

The only Navy owned supply facility is the Inventory Storage Center which is available to support depot maintenance. There are two Inventory Storage Centers, one for the Naval Eastern Region, located at Surabaya, East Java, and the other for the Naval Western Region, located at Jakarta, West Java. The function of the Inventory Storage Center is to provide spare parts and material for depot maintenance activities performed at the contractor facilities [Ref. 5:p. 25].

Spare parts needed for intermediate and organizational maintenance are being stocked at intermediate and organizational maintenance facilities.

The Indonesian government hopes that the shipyard contractors will expand after acquiring experience in maintaining and repairing a combat ship. In addition, it is hoped that the repair time might be shorter than it was previously when performed by Navy personnel.

The structural organization of the Fleet Commands associated with maintenance management is illustrated in Figure 2.2. Maintenance management in the Eastern and Western Fleets is performed by the Fleet Maintenance Department, and in the Military Sea Lift Command by the Material Department, under the supervision of Assistant Commandant, logistics staff. Intermediate maintenance is performed at each Base Maintenance Facility by the Base Maintenance Team.

Three additional teams, appointed annually, are associated with maintenance activities:

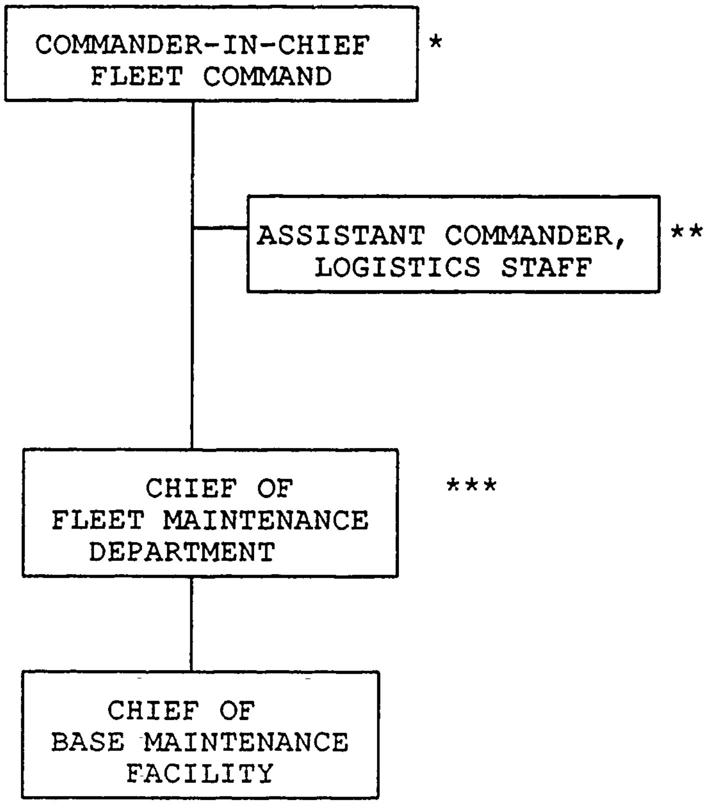
1. SHIP-CHECK TEAM

2. NEGOTIATION TEAM

3. LIAISON OFFICERS

The Ship-Check Team's function is to investigate failed items to determine the spare parts required for repairing them and to make a proposal to the Chief of the Fleet Maintenance Department regarding whether the failed item should be repaired at the intermediate or at the depot level. These actions are done quarterly and before major overhauls [Ref. 3:p. 31].

One of the Negotiation Team's functions is to calculate the Navy standard maintenance costs of the failed items and the costs of spare/repair parts that should be procured if not available in inventory. The team then compares these costs with those proposed by the contractor and negotiates these costs if they are considered to be too high.



Note:
For Military Sea Lift Command,
* = Commandant
** = Assistant Commandant, Logistics Staff
*** = Chief of Material Department

Figure 2.2: Organizational Structure of Fleet Maintenance Management in the Indonesian Navy

The liaison officers' functions are to monitor the progress of depot maintenance activities performed at the shipyard contractor's facility and to advise the contractor and Chief of the Fleet Maintenance Department about problems encountered during depot maintenance.

One of the most important tasks performed by the three teams is to find possible cost savings without sacrificing effectiveness. Since sophisticated cost analysis using trade-off studies, present value of money, and inventory models, etc., have not been conducted yet, it is sometimes difficult to achieve this goal satisfactorily.

D. THE NEED FOR MORE EFFECTIVE AND EFFICIENT MANAGEMENT OF MAINTENANCE

Since major weapon systems have become more complex as technology has advanced, logistics requirements in general have increased. At the same time decreasing budgets combined with upward inflationary trends have resulted in less money being available for maintenance and support of systems already in use.

One of the greatest challenges facing the Indonesian Navy today is the growing need for more effective and efficient management of resources. Experience has indicated that operation and maintenance costs constitute a large portion of the Navy's budget. The Indonesian Navy, like navies of other developing countries which usually buy fully developed weapon systems, is primarily concerned with the use period of life-cycle support. However, at the beginning of the use period there is an opportunity for the Indonesian Navy to perform life-support cost analysis relative to repair or discard decisions and maintenance level alternatives. The objective of this analysis is to minimize life-cycle maintenance costs. Models to perform this analysis are the subject of the following chapters.

III. SYSTEM LIFE-CYCLE AND COST-EFFECTIVENESS RELATIONSHIP

A. SYSTEM LIFE-CYCLE

A basic knowledge of the system life-cycle concept is fundamental to an understanding of the cost-effectiveness approach to be presented in this thesis. It is during the early phases of the system life-cycle that a system's effectiveness characteristics are determined, and these establish the quantitative basis for trade-offs between subsequent effectiveness and cost elements [Ref. 8:p. 19].

Any system is designed and produced to satisfy a need. Moreover, the system must be able to continue to meet the need over a specified period of time to justify the investment in time, money, and effort. Thus, one must consider a system in a dynamic sense–that is, from a life-cycle or so-called "cradle-to-grave" viewpoint [Ref. 8:p. 19].

The system life-cycle represents the phases through which any system passes, as well as the activities that take place during these phases.

The system life-cycle, as illustrated in Figure 3.1, starts with the Planning Period, during which the need for a new system is verified and system operational and maintenance concepts are formulated. The operational and maintenance environments and resources available are considered, and system feasibility is determined by consideration of operational, technological, economic, political, legal, and other factors. At the end of this period, the system is defined by a set of design requirements to meet operational needs [Ref. 8:p. 21].

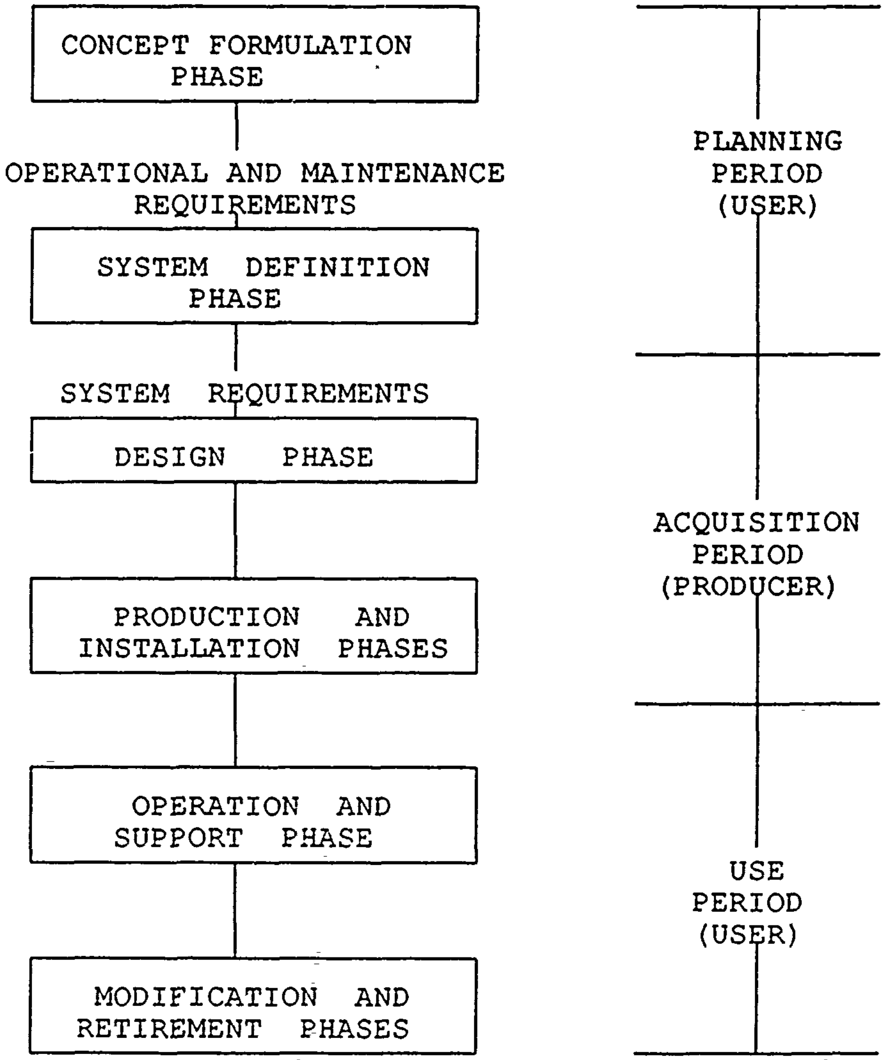


Figure 3.1: System Life Cycle [Ref. 8:p. 163]

The Acquisition Period includes the design, test, evaluation, production, and installation of the system. It is during the design phase that the effectiveness characteristics, specified as a set of requirements in the previous period, are converted into a hardware system that can be tested and verified. Some redesign and modification

of the system is often needed as a result of these tests. Prior to production, system specifications previously agreed upon by the customer and producer are demonstrated or modified as a result of a cost-effectiveness evaluation. The effectiveness value achieved and cost estimate for the system's operational period (e.g., operational availability and life support cost) must be accepted by both parties [Ref. 8:p. 22].

The Use Period includes all operation and support activities. This is the longest and most expensive period of the life-cycle. Sometimes changes are introduced into the system during this period as a result of problems detected from actual use in an operational environment. The Use Period ends with retirement of the system from active service because operation and support are no longer cost-effective.

The requirements for sustaining a system day-to-day are initially identified through the maintenance concept, and subsequently refined through logistic support analysis (LSA). The results of LSA, in terms of maintenance levels, personnel quantities and skills, and test and support equipment, are usually included in an integrated logistic support plan prepared before the start of the production phase and used as a basis for implementing a life-cycle support capability for the system throughout its operational-use phase.

B. COST-EFFECTIVENESS

The development of a system that is cost-effective, within the constraints specified by operational and maintenance requirements, is a prime objective. Cost-effectiveness analyses provide a conceptual framework and methodology for the systematic investigation of alternatives. Determining cost-effectiveness involves measuring each alternative in terms of cost (total expenditure during the life-cycle)

versus effectiveness (level of mission fulfillment). By applying this analysis procedure, it is possible to select the optimal alternative for achieving of the goals defined within the allowed constraints [Ref. 8:p. 23].

Of the two elements–cost and effectiveness–cost is easier to measure and handle because it can be expressed by a single monetary value. Effectiveness can be presented both in terms of certain parameters that have a clear-cut numerical representation and others that are not readily quantifiable.

Cost-effectiveness analyses, which are similar to the standard cost-benefit analyses employed in many industrial and business applications, can be expressed in various terms (i.e., one or more figures of merit) depending on the specific mission or system parameters that one wishes to measure. The prime ingredients of cost-effectiveness are illustrated in Figure 3.2 [Ref. 10:p. 20].

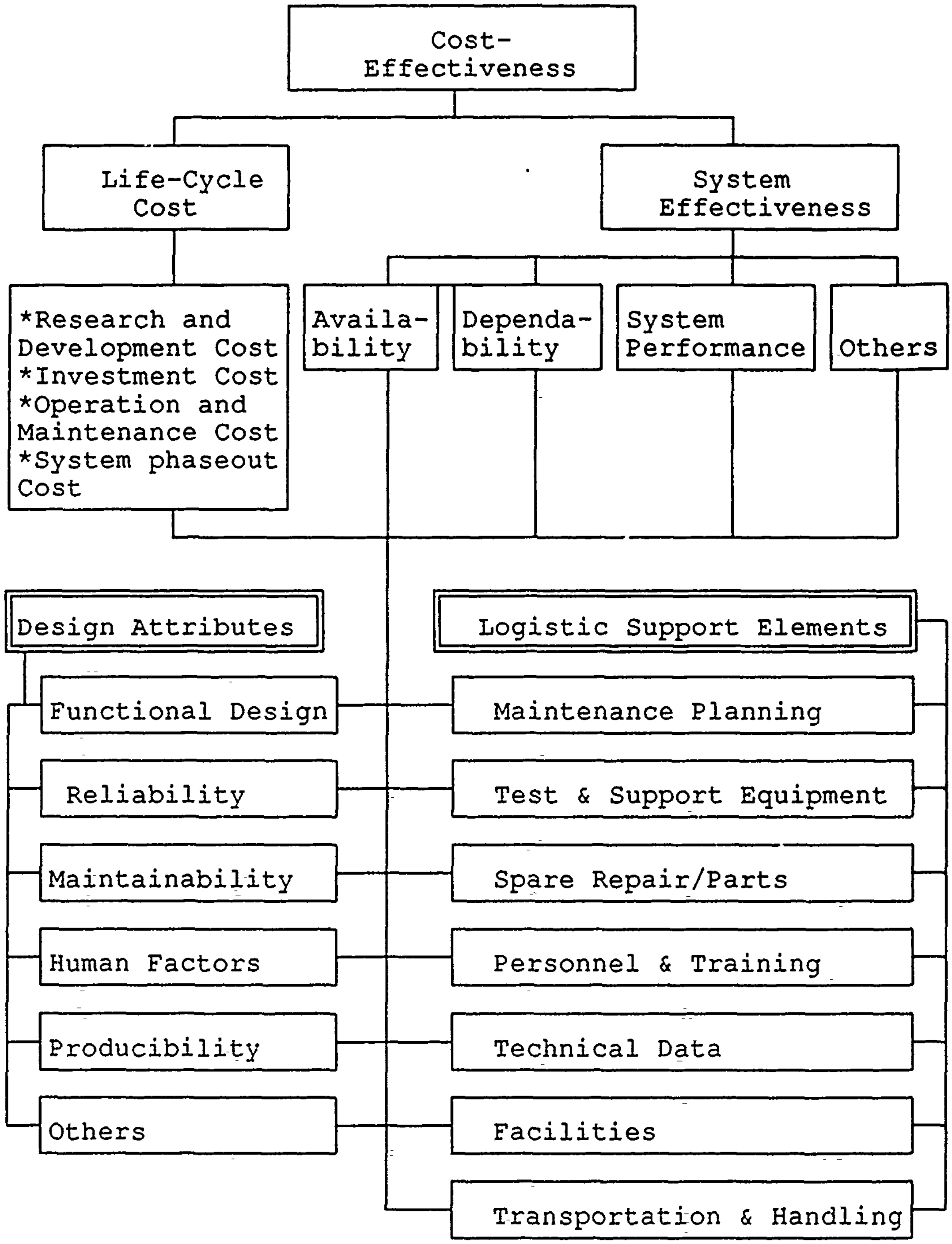


Figure 3.2: Basic Ingredients of Cost-Effectiveness [Ref. 10:p. 20]

1. System Effectiveness

According to Blanchard [Ref. 10:p. 18], system effectiveness is often expressed as one or more figures of merit representing the extent to which the system is able to perform the intended function (see Figure 3.2). The figures of merit used may vary considerably depending on the type of system and its mission requirements. Figures of merit may include [Ref. 10:p. 18]:

> *System Performance Parameters*, such as the capacity of a power plant, range or weight of an airplane, destructive capability of a weapon, quantity of letters processed through a postal system, amount of cargo delivered by a transformation system, and the accuracy of a radar capability.

> *Availability*, or the measure of the degree of a system is in the operable and committable state at the start of the mission when the mission is called for at unknown random point in time. This often called "operational readiness". Availability is a function of operating time (reliability) and downtime (maintainability/supportability).

> *Dependability*, or the measure of the system operating condition at one or more points during the mission, given the system condition at the start of the mission (i.e., its availability). Dependability is a function of operating time (reliability) and downtime (maintainability/ supportability).

System effectiveness is used as a predictive tool during the planning and design phase of the life-cycle, and should be evaluated continually as system development proceeds to insure obtaining an objective measure of fulfillment of system needs.

Of the three figures of merit listed above, availability is the most commonly used in military situations. There are three types of availability: inherent, achieved, and operational. The one considered most important for effectiveness evaluation purposes during the system's Use Period is operational availability (A_0)

since it is more closely related to the actual operational environment than the other two measures and is affected more by user decisions.

Operational availability can be defined as [Ref. 10:p. 65]:

> The probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon.

Operational availability can be expressed as:

$$A_0 = \frac{MTBM}{MTBM + MDT} ,$$

where

MTBM = mean time between maintenances, and

MDT = mean maintenance downtime.

When preventive maintenance downtime is not considered, MTBM becomes MTBF (mean time between failures), and operational availability can be expressed as [Ref. 11:p. 26]:

$$A_0 = \frac{MTBF}{MTBF + MDT} .$$

As stated above, availability concerns itself with operating time (reliability) and downtime (maintainability/supportability).

In dealing with maintenance problems, one must understand the concept of reliability. System reliability is usually expressed as a probability, and can be defined as [Ref. 10:p. 23]:

> The probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions.

A basic concept in reliability is the "Bathtub Curve" (see Figure 3.3), which represents the instantaneous failure rate. It consists of three regions: "infant mortality" where the failure rate is decreasing, constant failure rate, and "wearout region" where the failure rate is increasing. In the constant failure rate region, the times to failure can be described by an exponential distribution. In this region, the reliability over time t can be expressed as:

$$R = e^{-\lambda t} = e^{-t/MTBF} \quad ,$$

where

$t =$ Time period of interest ($t \geq 0$);

$\lambda =$ Instantaneous failure rate or frequency of corrective maintenance;

and

$MTBF =$ Mean time between failures $= \frac{1}{\lambda}$.

In determining system support requirements, the frequency of corrective maintenance (λ), or its inverse, $MTBF$, becomes a significant parameter. In general, as the reliability of a system increases, the $MTBF$ will increase. Conversely, the $MTBF$ will decrease as system reliability is degraded.

The second parameter of system availability is maintenance downtime (MDT) which is a function of maintenance and support activities. Maintenance involves activities directed toward failure prevention (preventive maintenance) and failure correction (corrective maintenance). A commonly used definition of maintenance is [Ref. 9:p. 63]:

> All actions necessary for retaining an end item in, or restoring it to, a serviceable condition.

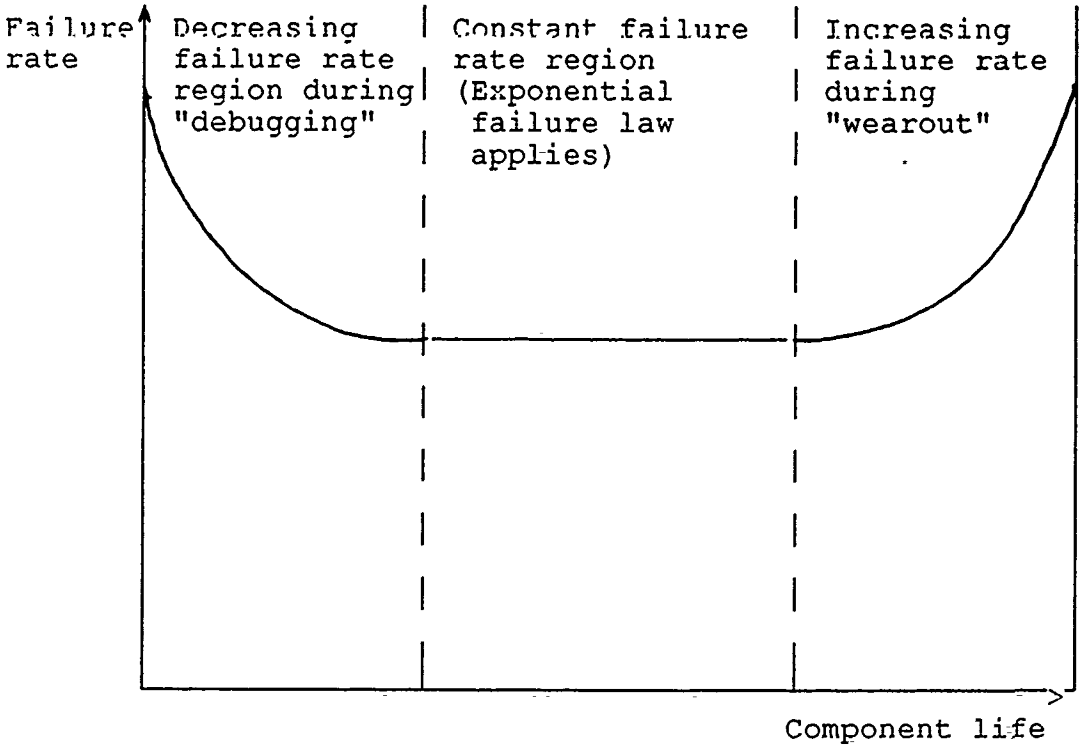


Figure 3.3: Typical Failure-Rate Curve [Ref. 10:p. 28]

Preventive or scheduled maintenance is often referred to as "retaining," while corrective maintenance is often referred to as "restoring." Preventive maintenance, on a scheduled basis to retain an item in satisfactory operating condition, includes servicing and inspection activities. Planning preventive maintenance involves selecting the manpower necessary to maintain the system, determining the time between periodic system inspections, and selecting items to receive preventive inspection at each succeeding period. All three activities should be combined to yield the least cost maintenance condition for the level of system operation required.

Corrective maintenance is that maintenance performed to return an equipment to service after a failure or other malfunction has occurred. It includes fault detection, diagnosis, correction, and verification.

The relationships among the primary subsets of preventive and corrective maintenance are illustrated in Figure 3.4 [Ref. 9:p. 54]. A further partitioning of corrective maintenance activities results in the identification of the more elementary tasks involved, including the secondary maintenance loop for rear echelon repair of removed items. These are illustrated in Figure 3.5 [Ref. 9:p. 55].

Maintenance downtime can be expressed as the sum:

$$MDT = \bar{M} + ADT + LDT \quad ,$$

where

$\bar{M}$ = Mean active maintenance time (sensitive to environment, technician skill level, procedures, etc.);

ADT = Administrative delay time (sensitive to administrative procedures, filing, storage, etc.); and

LDT = logistic delay time (time used in obtaining spares or repair parts or in waiting for personnel, manuals, tools, or test equipment).

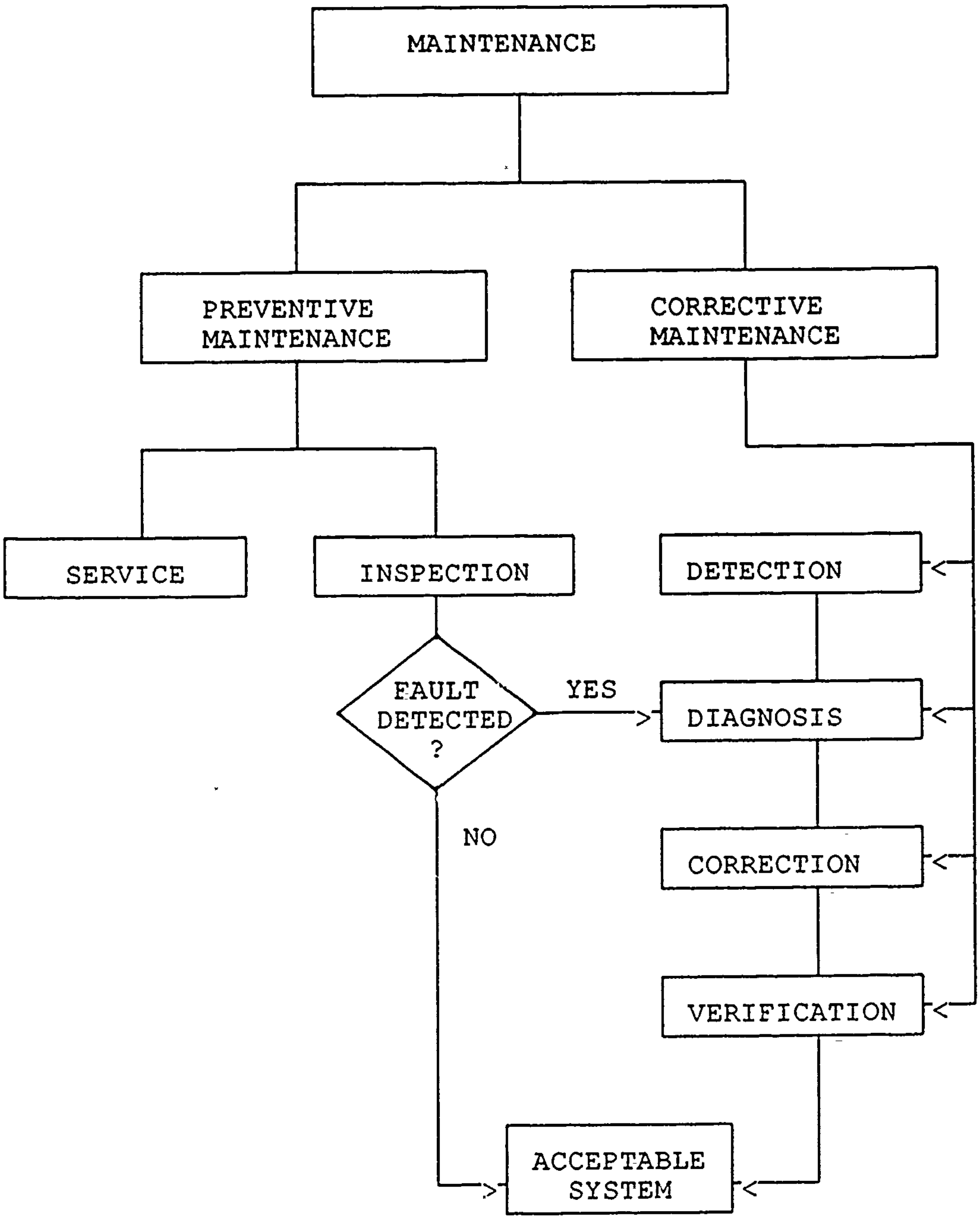


Figure 3.4: The Primary Subsets of Maintenance [Ref. 9:p. 54]

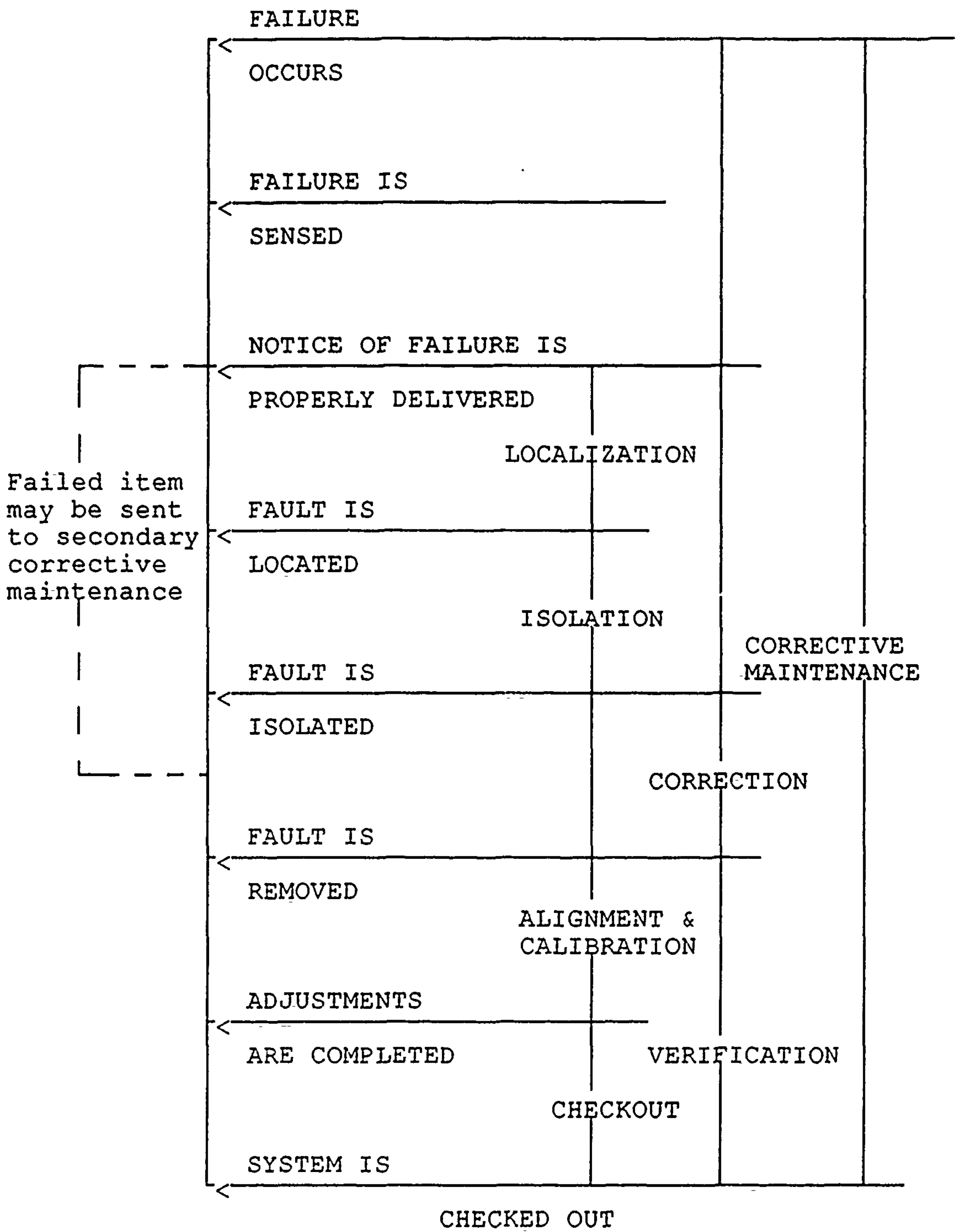


Figure 3.5: A Partitioning of Corrective Mainenance [Ref. 9:p. 55]

Mean active maintenance time ($\bar{M}$) is the time during which repair actions are being performed and is under the control of the maintenance technician. *ADT* and *LDT* represent delay times during which the maintenance technician may be able to do little or nothing toward actively restoring the equipment.

2. Life-cycle Costs

The life-cycle costs (LCC) of a system consists of all costs incurred during the complete system life-cycle. Development of the LCC for use in system evaluation is motivated by the fact that the major part of user budgets are spent on operations and support activities. Moreover, it is recognized that these costs may exceed system procurement costs by several times. Therefore, the main purpose of identifying the LCC is to enable trade-off analyses to be made which will result in savings during the Use Period. These savings may be offset by increased expenditures duı'ng the Acquisition Period. However, the goal is the lowering the system's total costs [Ref. 8:p. 27].

According to Blanchard [Ref. 10:p. 19], LCC involves all costs associated with the system life-cycle, including research and development (R&D), production and construction, operation and maintenance, and system retirement and phaseout (see Figure 3.6).

> *Research and development (R&D) cost* – the cos' of feasibility studies; system analysis, detail design and development, fabrıcation, assembly, and test of engineering models; initial system test and evaluation; and associated documentation.

> *Production and construction cost* – the cost of fabrication, assembly, and test of operational systems (production model); operation and maintenance of production capability; and associated initial logistic support requirements (e.g., test and support equipment development, training, entry of items into the inventory, facility construction, etc.).

Operation and maintenance cost – the costs of sustaining operations, personnel and maintenance support, spare/repair parts and inventory, test and support equipment maintenance, transportation and handling, facilities, modification and technical data changes, and so on.

System retirement and phaseout cost – the cost of phasing the system out of the inventory due to obsolescence or wearout, and subsequent equipment item recycling and reclamation, as appropriate. [Ref. 10:p. 19]

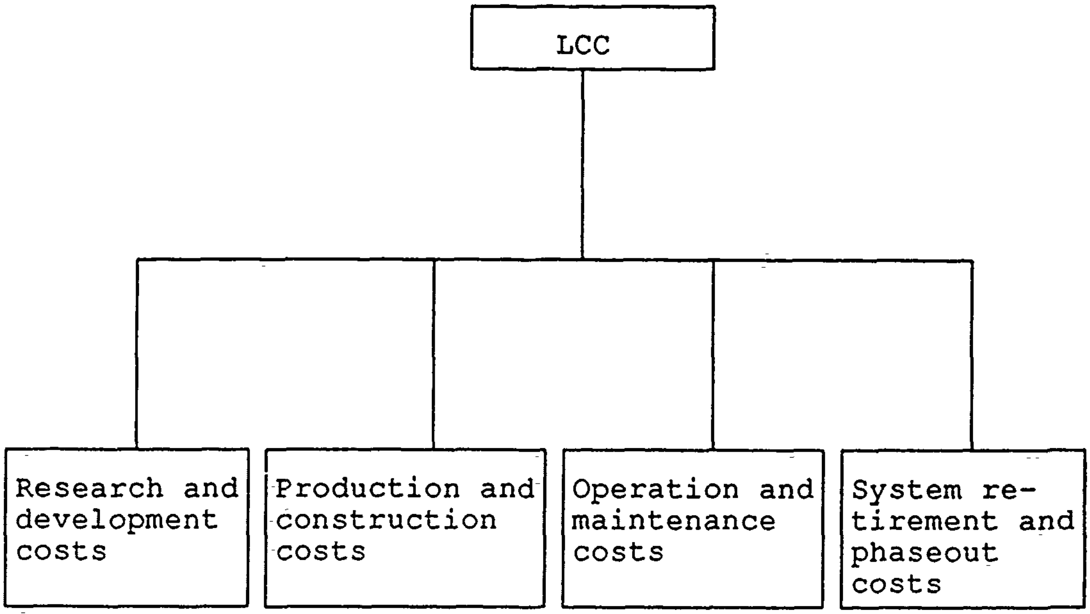


Figure 3.6: Life-cycle Costs [Ref. 10:p. 19]

C. LIFE-SUPPORT COSTS IN RELATION TO MAINTENANCE LEVEL ALTERNATIVES AND REPAIR/DISCARD DECISIONS

Life-support costs (LSC) are the costs of operation and maintenance (i.e., all costs necessary to support and maintain a system during the operational and support phase of its life- cycle). LSC is dependent on operational requirements, system characteristics, existing maintenance levels, stockage policy, and maintenance policy

in terms of maintenance level and repair/discard decision. In the case of maintenance policy, a trade-off analysis must be performed to select the maintenance level alternative and discard decision that will yield the least expected maintenance costs.

For example, consider a policy that requires isolation of equipment failure to the assembly level, removal of the faulty assembly and replacement with a serviceable spare. If the faulty assembly can be easily isolated from the indications of the equipment's condition, the corrective-maintenance labor required may be small, the skill level required may be low, the corrective-maintenance downtime may be small, and no general or special test equipment is required. If the failed assembly is thrown away, the maintenance costs for repairing the failed assembly are saved (i.e., the labor costs, the processing and procurement costs of the spare parts, the processing costs of returning the failed assembly to a repair facility, and the costs of general and special test equipment).

However, this policy incurs both the processing and procurement costs of providing replacement assemblies and a supply downtime penalty should all onboard replacements be exhausted. These assembly, procurement and processing costs depend on the number of assemblies purchased over the equipment service life and on the price of each assembly. It is necessary to provide at least one replacement assembly per failure for this policy.

Conversely, if the failed assembly is repaired aboard ship (organizational level), assuming that the equipment has been made serviceable with a spare assembly, and both general and special test equipment are required to repair the failed assembly, the corrective-maintenance labor, the skill level of the technician, and the test equipment requirements may be high, but equipment downtime due to corrective maintenance does not change. Hence, the shipboard maintenance burden is increased and both the processing and procurement costs of spare parts are incurred,

but the processing cost of returning the failed assembly to a repair facility is saved. In addition, the processing cost of providing replacement assemblies is reduced, because once these assemblies are repaired, they become serviceable shipboard replacements. Therefore, fewer assemblies need to be purchased over the equipment service life than those for the throw-away (discard) policy.

Next consider the decision to repair the failed assembly at a shore-based repair facility (intermediate level), again assuming that the equipment were made serviceable with a spare assembly. The shipboard maintenance burden and the corrective-maintenance downtime remain the same as those of the discard policy. However, labor and test equipment costs to repair the failed assembly, and both processing and procurement costs of spare parts, applicable to the shore-based repair facility, are incurred. In addition, both the processing costs of obtaining another serviceable spare assembly and of returning the failed assembly to the repair facility must be paid. A supply downtime penalty can occur should all onboard replacements be exhausted.

Thus, there are the trade-offs among the above alternatives that will yield the optimal decision. Other factors that influence the trade-off analysis, such as system indenture levels and component and sub-component failure rates, will be considered in the next chapter.

IV. THE FRAMEWORK OF LEVEL OF REPAIR ANALYSIS

A. INTRODUCTION

Level of repair (LOR) decisions influence the logistic support costs and system effectiveness of weapon systems. LOR decisions also influence the maintenance plan and integrated logistic support (ILS) elements necessary to maintain the operational readiness of the hardware system.

LOR analyses are based on operational factors such as operating hours, support factors (such as maintenance action rates and maintenance times and costs) and non-economic factors. The purpose of this analysis is to establish the least-cost feasible repair or discard decision alternative for performing the maintenance actions.

The two basic questions are:

1. Which parts of the system should be designed as a repairable or nonrepairable module (discard at failure)?

2. If the module is designed as repairable, at what level of maintenance should it be repaired?

In the U.S. Navy, these questions can be answered during the research and development (R & D) phase. LOR analyses, recommendations, and decisions for new material should be made as soon as the equipment's preliminary design has been determined.

For the navies of developing countries, such as the Indonesian Navy, which are not involved in the R&D phase, these questions should be answered before

initial deployment of the weapon systems. In that case the first question should be modified slightly as follow: Which parts of the existing system should be repaired or discarded?

According to Military Standard, LOR Analysis, MIL-STD-1390C, there are two basic types of LOR analyses: economic and non-economic [Ref. 12:p. 13]. An economic analysis is a method of collecting and computing the logistic costs associated with maintenance alternatives from which LOR recommendations can be made. This type of analysis consists of computing various cost elements for discard and all repair alternatives, summing these elements by alternatives, comparing the sums and selecting the lowest cost alternative.

Economic LOR analytical techniques are based upon six major cost categories [Ref. 12:p. 151]:

1. Inventory, which includes level of investment, attrition, administration, and storage space;
2. Personnel, which includes training and direct labor;
3. Support equipment, which includes acquisition, support, and space;
4. Repair, which includes material, scrap, and space;
5. Documentation;
6. Transportation, which includes packaging, and shipping.

The analysis performed incorporates several factors when establishing feasible alternatives. These include [Ref. 12:p. 69]:

1. The inherent failure and repair characteristics of an item;
2. The indenture level or parts breakdown for discard, remove and replace, and repair actions;
3. The minimum maintenance level capable of performing these actions.

The output of economic LOR analysis determines whether the item should be discarded or repaired at the depot, intermediate, or organizational level.

The second type of LOR analysis is a non-economic analysis which evaluates significant non-economic factors from which LOR decisions can be made. This type of analysis does not take into account cost considerations, but instead, considers factors such as safety, readiness, policy, and mission success. Any LOR recommendations based upon this type of analysis should also include an economic analysis so as to assign some economic value to the non-economic recommendation.

B. CLASSIFICATION OF EQUIPMENT INTO INDENTURE LEVELS

The equipment under analysis may be classified into four or more indenture levels. For the purpose of analysis in this thesis, the equipment or system will be divided into four indenture levels, as follows [Ref. 12:p. 108]:

1. Equipment (system)
2. Weapon replaceable assembly (WRA)
3. Shop replaceable assembly (SRA)
4. Sub-SRA

The classification of equipment into indenture levels is illustrated in Figure 4.1. Maintenance alternatives for the assemblies (modules) of the equipment under analysis are selected through LOR code assignments. The code assignment procedure is illustrated in Figure 4.2 [Ref. 12:p. 110] and is described below.

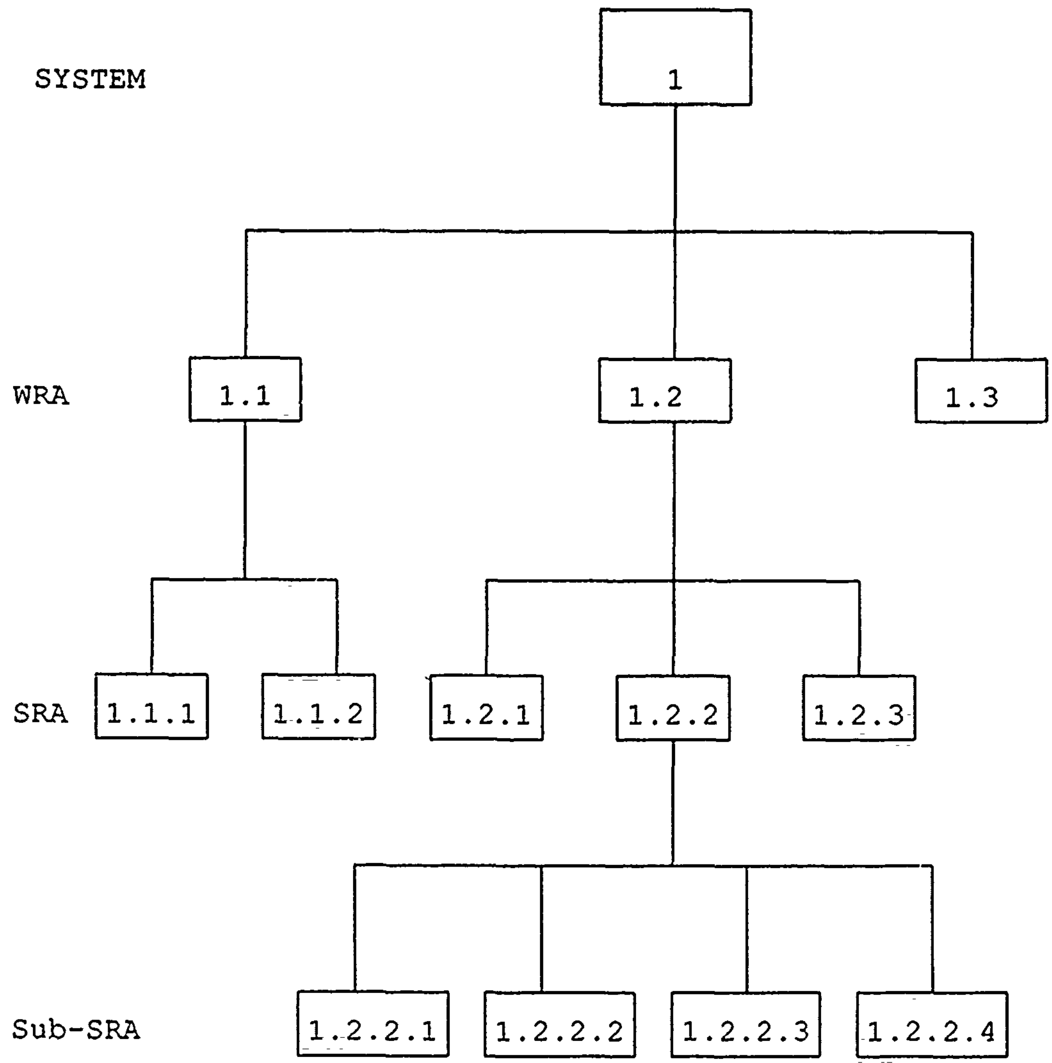


Figure 4.1: Equipment Indenture Levels

According to MIL-STD-1390C, there are some assumptions and inherent limitations on the assignment of LOR codes [Ref. 12:p. 111].

1. Assumptions

An LOR code assigned to an item is independent of which indenture level part caused the failure.

Discard at failure is performed at the organizational level.

2. Limitations

A maintenance alternative is defined as a particular set of LOR cases for all the items where higher assemblies are not discarded [Ref. 12:p. 111]. This means that if a higher assembly is assigned for discard, the lower assemblies associated with it are not considered for LOR assignment.

No subassembly can be assigned to a repair facility level lower than the assembly including it [Ref. 12:p. 111]. This limitation applies to complete assembly repair, because alignment and calibration must wait until subassemblies have been repaired. In fact, manhours per given maintenance action at a higher maintenance level are fewer than at a lower maintenance level. Thus, to achieve the shortest waiting time, the subassemblies should be repaired at a higher maintenance level, or at least at the same level as their assemblies.

Each item of assembly indenture classification may be assigned one of three LOR codes: I (intermediate), D (depot repair), and X (discard). The LOR alternatives depend on the structure of the existing maintenance levels, geographical locations, operational requirements, and the nature of the hardware system's physical design configuration. These conditions will affect the LOR code assignment and the cost equations for the analysis of repair alternatives.

Figure 4.2 presents the three alternatives for the WRA. For each alternative, the SRA alternatives based on the assumptions and limitations are shown. Finally, for each SRA alternative, the sub-SRA alternatives are shown. If a WRA is assigned to depot repair (D1, see Figure 4.2), then the only choices available for its SRAs are

depot repair (D2) and discard (X3). If a WRA is assigned for discard (X4), the lower assemblies associated with this WRA are not considered for LOR code assignment. Similarly, if an SRA is assigned for discard (X3 or X5), the lower assemblies (SRAs) associated with this WRA are not considered for LOR assignment.

Within the existing maintenance levels of the Indonesian Navy, three LOR alternatives may be considered for each indenture level:

1. Intermediate repair;

2. Depot repair, associated with designated shipyard contractors;

3. Discard at failure, equivalent to organizational repair.

C. EXISTING MAINTENANCE LEVELS OF THE INDONESIAN NAVY

The LOR code assignment and the cost equations developed in this thesis will be based on those conditions associated with the existing maintenance levels of the Indonesian Navy.

As discussed in Chapter II and shown in Figure 4.3, the maintenance function at the depot level is performed by the shipyard companies selected by the Indonesian Navy. The Indonesian Navy has six designated contractors to perform depot maintenance. The only special storage facilities within the Indonesian Navy are the Inventory Storage Centers which are only available to support depot maintenance. There are two Inventory Storage Centers, one for the eastern region, and the other for the western region.

Intermediate maintenance is performed by specialized installations located at the shore-base facility of each Fleet Command. The three Intermediate maintenance facilities are:

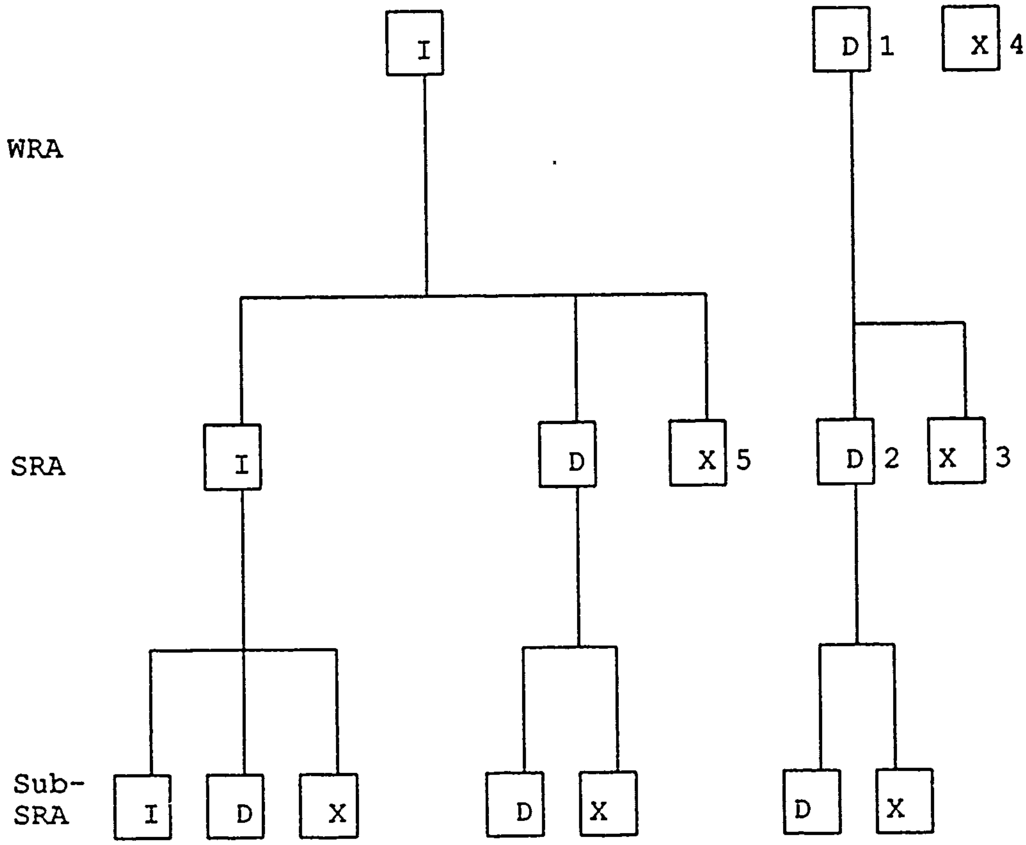


Figure 4.2: LOR Code Assignment Procedure [Ref. 12:p. 110]

1. Intermediate facility of Eastern Fleet

2. Intermediate facility of Western Fleet

3. Intermediate facility of Military Sea Lift Command

Figure 4.3 emphasizes that intermediate facilities are independent or separate, having no horizontal support relationship with the other intermediate facilities.

At the organizational level of each Fleet Command are the ships and squadrons. The Military Sea Lift Command differs slightly, having at the organizational level ships and shore stations.

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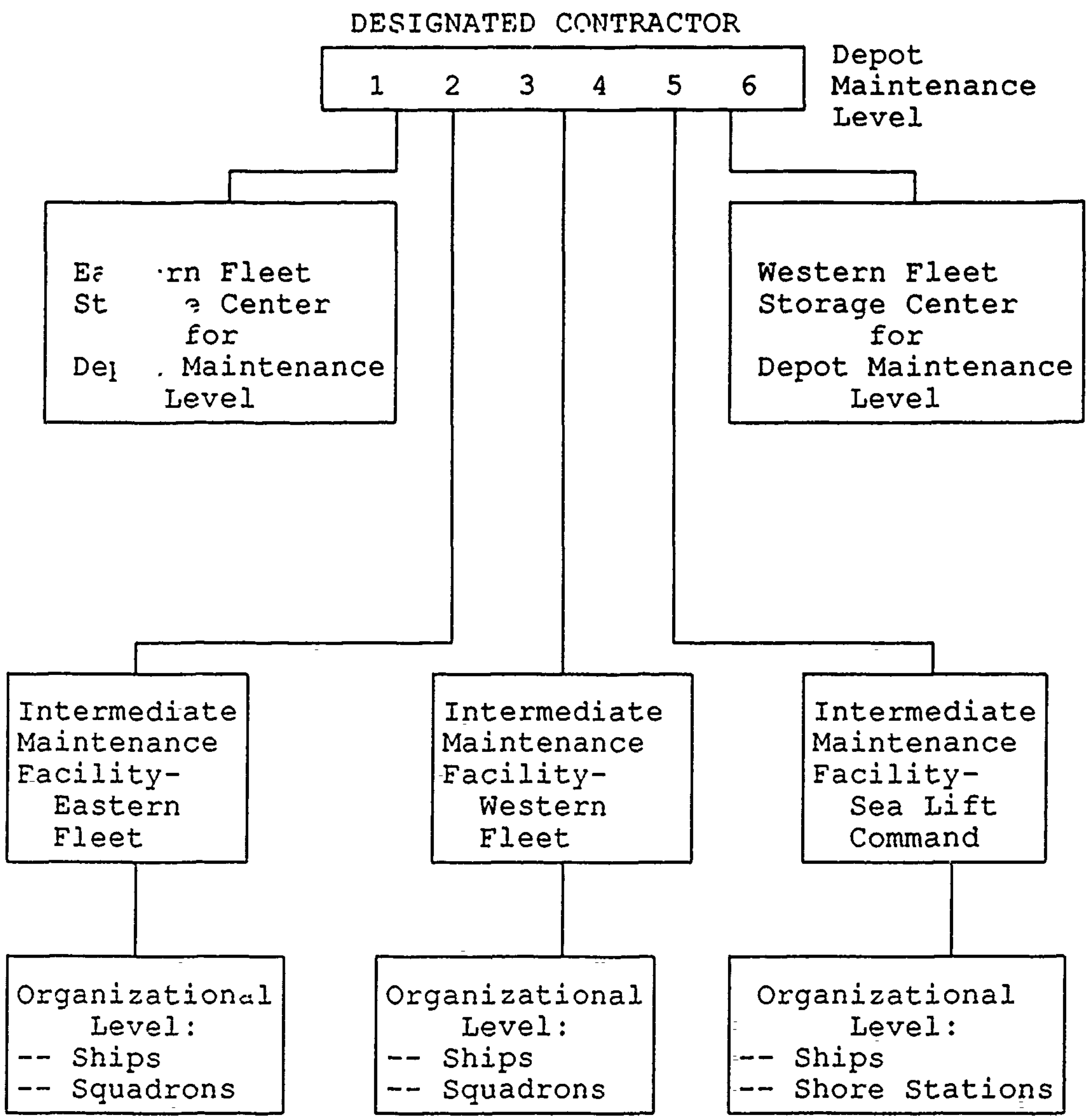

Figure 4.3: Existing Maintenance Levels in the Indonesian Navy

D. THE OPTIMIZATION PROCEDURE

Some of the allocatable costs depend on the LOR of the assembly (module) and on that of its next higher assembly. These possible assignments are:

Table 4.1: Assignments of Assembly

Case	Assignment of Assembly (Module)	Assignment of Next Higher Assembly
(1)	IMA	IMA
(2)	Depot	IMA
(3)	Discard	IMA
(4)	Depot	Depot
(5)	Discard	Depot
		Discard

The three or five costs corresponding to the different assignments are computed for each assembly and its next higher assembly, if applicable.

The optimization procedure is initiated by finding for each sub-SRA the optimal LOR assignment for each possible assignment of its SRA. For example, the optimal assignment of a sub-SRA, given that its SRA is assigned to IMA (intermediate maintenance level). is the smallest cost from cases (1) through (3) in the table above. If the SRA is assigned to depot, it is the smallest cost of cases (4) and (5).

For every possible LOR of an SRA, the optimal assignments of its sub-SRAs are determined along with their costs.

The next step is to find the optimal assignment of each SRA. The life-support costs of the SRA are already available from step one. For each possible assignment of a WRA, the optimal assignment of each of its SRAs is found, considering both the SRA costs and the costs of the optimal assignment of their sub-SRAs. Having found the optimal support costs for each WRA, considered at each level of repair, the costs of the optimal assignment of its SRAs are summed.

The final step is to find the optimal assignment of a WRA, considering the costs of its SRAs and sub-SRAs. The following three quantities are calculated:

1. The LSC for the WRA, if assigned to an IMA, plus the sum of the optimal costs for all its SRAs and sub-SRAs, given this assignment.

2. The LSC for the WRA, if assigned to a depot, plus the sum of the optimal costs for all its SRAs and sub-SRAs, given this assignment.

3. The LSC if the WRA is discarded.

The smallest of these costs determines the LOR for the WRA and its subassemblies.

E. THE COMPONENTS OF LIFE-SUPPORT COSTS

This section will specify the mathematical equations for performing LOR analyses for equipment being analyzed under the current operational requirements and the existing maintenance organization of the Indonesian Navy. The equations determine the life-support costs (LSC) associated with the module or assembly indenture level.

The costs considered in determining a desired maintenance policy can be divided into two categories: initial investment costs (initial costs) and annual operating costs (recurring costs). These cost elements can be further divided into the following categories:

1. Maintenance manpower (labor)
2. Inventory for spare modules (assembly)
3. Repair material
4. Support equipment
5. Transportation
6. Training

Since this thesis is concerned with the cost of logistic support in the operational-use phase, only cost elements that normally are considered in any estimate of LSC for a system already designed will be considered.

The general assumptions on which the model is based are as follows:

1. The demand for spare modules is generated by failure of on-line modules during the operational-use phase.
2. The module failures are Poisson-distributed over time.
3. Only cost elements which normally are considered for systems already designed will be considered.
4. Only cost elements that vary from alternative to alternative are included in the calculations or cost equations.

5. Annual costs charged against inventory, test and support equipment, repair material, etc., are assumed to include the following:

   (a) Holding costs

   (b) Supply administration costs

   (c) Costs of obsolescence

In developing cost equations, one should use logical cost estimating relationships that broadly relate variour systems parameters to cost generation. The cost equations for evaluating alternatives on the basis of such cost estimating relationship of LSC, subject to the assumptions listed, will be presented below.

1. Maintenance Manpower Cost

The major maintenance manpower costs considered are those associated with the active maintenance time (i.e., the time required for detection, diagnosis, correction, and verification). The time required is equal to the number of manhours required and depends on the number of maintenance actions.

Normally, the annual maintenance manpower cost equation can be expressed as:

$$\begin{matrix}\text{Maintenance} \\ \text{Manpower Cost}\end{matrix} = \begin{matrix}\text{Number of} \\ \text{Maintenance} \\ \text{Actions per} \\ \text{Year}\end{matrix} \times \begin{matrix}\text{Manhours} \\ \text{Per} \\ \text{Action}\end{matrix} \times \begin{matrix}\text{Cost} \\ \text{Per} \\ \text{Manhour}\end{matrix}$$

The number of corrective maintenance actions is equal to the average number of item failures per year. The average number of annual failures of an item

where

DF = The discount factor;

i = The annual interest rate; and

y = Number of years per life-cycle.

Therefore, the present value of the total life-cycle manpower costs will be:

$$MPCD = ANF \times (MHRD \times HRD + TSI \times HRI + TSO \times HRO) \times DF \ ,$$

$$\begin{aligned} MPCI &= ANF \times [\, MHRI(1 - BCMI)HRI + MHRD(BCMI)HRD \\ &\quad + (TSO)HRO \,] \times DF \ , \end{aligned}$$

and

$$MPCO = ANF \times TSO \times HRO \times DF \ .$$

2. Inventory Costs

Inventory costs consist of initial costs and recurring costs. Initial costs are the cost of purchasing the initial stock of spare modules (assemblies) for the system, analogous to the first year's setup costs [Ref. 11:pp. 99-105]. Recurring costs are the costs of modules used up during operations. In the case of repair, this is determined by the condemnation rate. In the case of discard, the failure rate determines the number of modules used.

The determination of inventory stocking levels depends on the inventory policy of the existing organization. The major inventory policies of the Indonesian Navy are based on maintenance criticality. Although the Indonesian Navy uses maintenance criticality in its inventory policy, determination of the inventory stocking levels is not clearly defined yet. The inventory stocking level is usually determined by a simple forecasting method that involves averaging the historical data regarding demand.

In the U.S. Navy, inventory levels are determined through various mathematical models involving costs and demand probability distributions. So far, such models are not used by the Indonesian Navy.

Unfortunately, in the Indonesian Navy the amount of inventory in certain areas is higher than required resulting in higher inventory costs. On the other hand, stock-outs for certain spare parts frequently occur, resulting in decreased system effectiveness or reduced readiness of weapon systems. Thus, the Indonesian Navy needs an appropriate method for balancing these surpluses and shortages.

The U.S. Navy determines the initial inventory of stock using the level of protection concept, based on the Poisson distribution. The protection interval is the inventory system resupply time which will be denoted here as TAT. If P is the desired goal for the percentage of demands to be filled over TAT, then the number of units to be procured to meet this goal is the minimum value of Nc for which

$$\sum_{x=0}^{Nc} \frac{(K)^x}{x!} e^{-K} \geq P \ ;$$

where

$$K = \frac{N \times TAT}{MTBF} \ .$$

For the depot level, Nc will be defined further as Ncd, for the intermediate level, as Nci, and for the organizational level, as Nco.

The average annual system stock quantity (AASS) for a given repair policy can be defined as a quantity of modules required to replace the average number of modules which could not be repaired. This quantity can be determined by the condemnation rate at the depot level or the discard rate (because the unit of the item can not be repaired) and BCM rate at a lower maintenance level.

If the depot alternative is chosen, the average annual stock quantity is determined as:

$$\text{AASSD} = \begin{array}{c}\text{Average Annual}\\ \text{Item Demand}\end{array} \times \begin{array}{c}\text{Depot}\\ \text{Discard Rate}\end{array}$$

or

$$AASSD = ANF \times DCRD$$

For the intermediate alternative, the average annual stock quantity is determined as:

$$\text{AASSI} = \begin{array}{c}\text{Average Annual}\\ \text{Item Demand}\end{array} \times \begin{array}{c}\text{Intermediate}\\ \text{(Discard Rate}\end{array} + \begin{array}{c}\text{Intermediate}\\ \text{BCM Rate)}\end{array}$$

or

$$AASSI = ANF \times [DCRI + BCMI]$$

If the U.S. Navy's level of protection model is used to determine the initial stock level, the present value of the total life-cycle inventory costs of spare modules (INVC) for each repair policy alternative can be expressed as follows for the depot repair alternative:

$$INVCD = [Ncd + ANF \times DCRD \times DF] \times UC \ .$$

For the intermediate repair alternative:

$$INVCI = [Nci + ANF \times (DCRI + BCMI) \times DF] \times UC \ .$$

The annual stock quantity for the discard (at the organizational level) policy is determined by the average number of item failures per year [Ref. 12:pp. 179]. The initial stock quantity for discard policy is equal to Nco. Therefore, the total life-cycle inventory costs of spare modules for discard policy can be expressed as:

$$INVCO = [Nco + ANF \times DF] \times UC \ .$$

3. Repair Material Costs

Repair material costs are the costs of materials (gaskets, nuts, bolts, piece parts, etc.) utilized to repair modules that have failed. For the complete discard alternative, the repair material cost is zero since no repair parts are required. For the other alternatives, the repair material costs consist of an initial cost for establishing an inventory and annual recurring costs to replenish the inventory [Ref. 11:p. 114]. The initial cost to procure an inventory of repair material is not considered in either of the LOR analyses of the Naval Sea Systems Command [Ref. 12:p. 168] or in the U.S. Marine Corps [Ref. 12:p. 187]. However, for the purposes of this thesis the initial cost of repair material will be considered as necessary to give an initial protection level for repair material stock.

The equations for repair material can be inferred from the equations for inventory modules cost ($INVC$), adjusted by a cost factor (CF). The cost factor is determined as a percentage of the unit cost of module. For example, an electronic module consists of a various electronic components (i.e., diodes, transistors, resistors, integrated circuits, etc.) and other material (i.e., gaskets, nuts, bolts, etc.) that make up the module. When a module has failed, it is estimated that a percentage of the components that made up a module will have also failed. Therefore, new components are needed to replace the worn- out components. Based on experience the percentage of these worn- out components can be estimated to be between 10% to 25% [Ref. 11:p. 114]. The initial repair material cost for a given repair policy can be expressed as:

$$IRMC = Nc \times CF \times UC \ .$$

The total life-cycle costs for the recurring needs for repair material for the depot repair policy are determined as:

$$ARMCD = ANF \times (1 - DCRD) \times DF \times CF \times UC \ .$$

The total life-cycle costs for the recurring needs for repair material for the intermediate repair policy can be determined as:

$$ARMCI = ANF \times [1 - (DCRI + BCMR)] \times DF \times CF \times UC \ .$$

Finally, the present value of the total life-cycle repair material costs for each repair policy is the sum:

$$RMC = IRMC + ARMC \ .$$

4. Support Equipment Costs

Generally, the support equipment (including the test equipment) is available at the beginning of the program. There are also annual recurring costs that will be incurred to maintain this support equipment. The annual recurring costs to be considered here include the cost of material and labor for repair and the cost of replacing support equipment that cannot be repaired.

The average annual support equipment costs will be assumed to be a percentage (PC) of the total capital cost (CSE) or the initial cost to buy the support equipment. At the beginning of the program money must be allocated for the initial cost of the support equipment. This allocation is usually estimated as a percentage of the total project's budget. For the discard alternative, the utilization of support equipment will be minimal since no repair is performed at the organizational level. It would be used for removal and preparation for disposing of the discarded components. Thus, the average annual support equipment costs for the discard alternative will be smaller than that of the intermediate or depot alternative.

Given the existing maintenance levels of the Indonesian Navy, if depot repair is chosen, the initial costs of depot support equipment and recurring annual costs will be charged by the designated contractor. Navy support equipment will be needed only for removal and shipping preparation at the organizational level. The intermediate level costs will be more visible.

The present value of the total life-cycle support equipment costs for each alternative can be expressed as the following:
For the discard alternative:

$$SECO = CSEO \times (1 + PCo \times DF)$$

For the intermediate alternative:

$$SECI = SECO + CSEI \times (1 + PCi \times DF) \ .$$

For the depot alternatives:

$$SECD = SECO + CSED \times (1 + PCd \times DF) \ .$$

5. Transportation Costs

The transportation costs are computed as the expenses incurred in shipping inventory items between maintenance levels, including the packaging costs. In the case of repair, these costs are incurred during the life-cycle as a consequence of sending failed modules from the operational site to the maintenance level, the repaired modules from the maintenance level to the operational site, and the BCM modules between maintenance levels.

For the discard alternative, no transportation costs for failed modules are incurred since these modules are discarded at the operational site.

No transportation costs for spare modules are incurred because spare modules for any of the repair or the discard policies are stocked at the organizational level.

The transportation costs will be considered to be recurring, computed as the function of annual item failures, assembly weight, and the shipping cost per pound. In the existing maintenance levels of the Indonesian Navy, the transportation costs incurred by the depot maintenance level are higher than the transportation costs at the intermediate and organizational levels because of the distance factor and the designated contractor's standard cost of transportation.

If the depot repair alternative is chosen, the equation for the present value of the total life-cycle transportation cost (TRPC) is as follows:

$$TRPCD = ANF \times WAS \times DF \times CPD \quad ,$$

where

WAS = Weight of an assembly in pounds; and

CPD = Shipping cost per pound from the organizational level to the depot level.

For the intermediate repair alternative:

$$TRPCI = ANF \times (CPI + BCMI \times CPM) \times WAS \times DF \quad ,$$

where

CPI = Shipping cost per pound from the organizational level to the intermediate level; and

CPM = Shipping cost per pound from the intermediate level to the depot level.

6. Training Costs

The training costs will be computed in two parts: initial costs and recurring costs. The initial costs are required to reflect the number of personnel that

need to be recruited and trained in the first year of the program. The recurring annual costs are due to the training of replacements due to personnel attrition.

In the LOR analysis of the U.S. Naval Sea Systems Command [Ref. 12:p. 166], the training costs are computed as a function of annual number of manhours required without showing the relationship between the annual number of manhours required and the number of personnel requiring training. Nielson and Shahal [Ref. 8:p. 229] argued that the training cost has no relationship to the number of manhours required.

In the author's opinion, the training costs should have a relationship to the number of manhours required. Therefore, the annual number of personnel required to be trained will be computed from the relationship between annual manhours required and annual duty hours per person (i.e., annual manhours required divided by annual duty hours per person (ADHR) is equal to the number of personnel required). Annual duty hours per person are equal to the duty hours per person per day (DHPD) multiplied by the number of effective repair days per year (EDPY). Therefore, the formulas for computing the initial training cost can be expressed as the following:

For the intermediate alternative:

$$ITRNCI = \left[\frac{(ANF \times MHRI)}{(ADHR)}\right] \times CPT \ .$$

For the discard alternative:

$$ITRNCO = \left[\frac{(ANF \times MHRO)}{(ADHR)}\right] \times CPT \ ,$$

where

CPT = Training cost per person.

If the depot repair alternative is chosen, the number of Navy personnel to be trained for depot repair would be zero since repair is performed by the designated contractor.

The present value of the total life-cycle costs associated with recurring training to replace those Navy personnel who retire or resign can be expressed as:

$$RTRNC = ATR \times ITRNC \times DF \times CPT \ ,$$

where

ATR = Personnel attrition rate.

Therefore, the present value of the total life cycle training costs for each policy can be computed from:

$$TRNC = ITRNC + RTRNC \ .$$

V. AN EXAMPLE OF LOR ANALYSIS

A. THE EXAMPLE SYSTEM

The optimum level for the repair alternative for a weapon system can be determined using the model developed in Chapter IV. The basic question is, "Should the failed item be repaired at depot level or intermediate level, or is it more economical to discard it at the organizational level?" This chapter will be concerned with illustrating the computation of life-support costs for assemblies in a hardware system to find the least maintenance cost.

The hardware system to be analyzed will be a simple radio transmitter. This simple example requires a relatively small number of computations, but should illustrate the LOR analysis method.

1. System Configuration of the Example

The system being analyzed is a transmitter whose configuration is illustrated in Figure 5.1. The transmitter is divided into three indenture levels: WRA, SRA, and sub-SRA. The WRA indenture level consists of:

1. PSA (1.1) = Power Supply
2. DRIV (1.2) = Driver
3. MOD (1.3) = Modulator
4. PA (1.4) = Power Amplifier

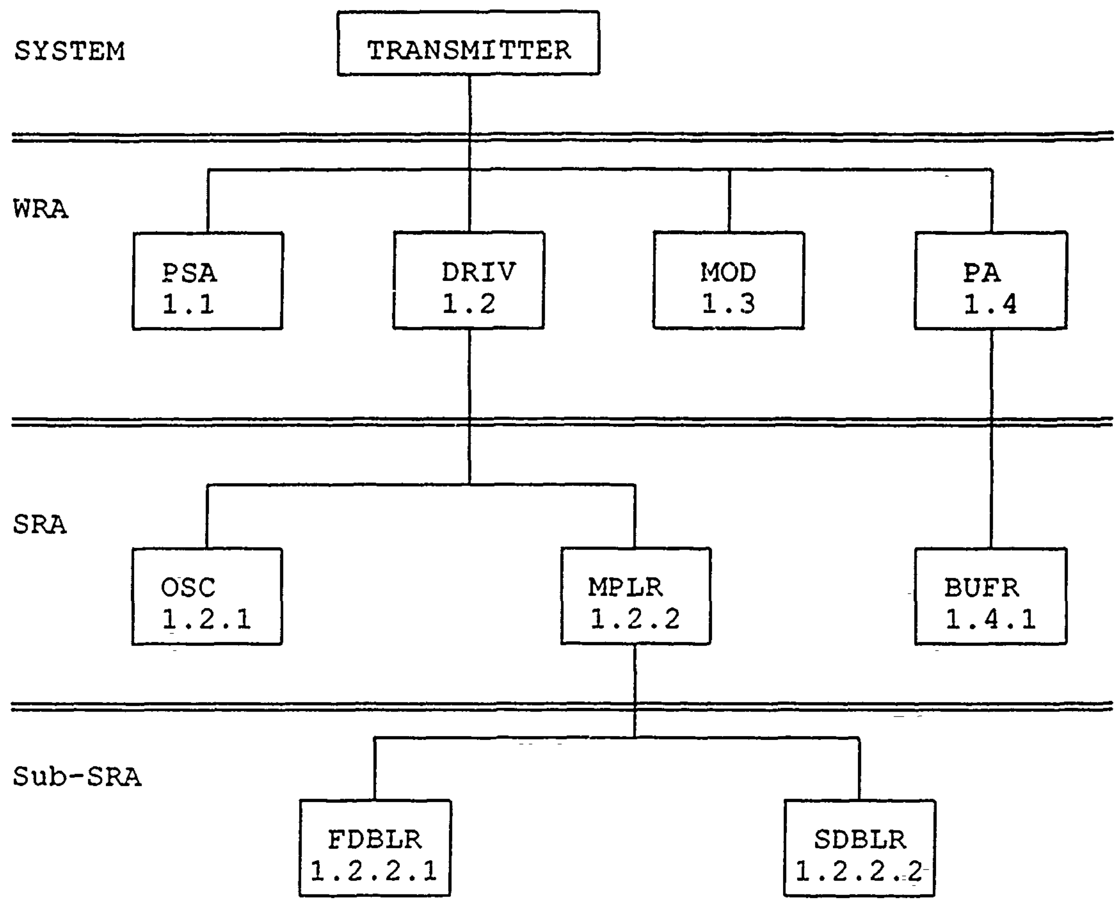

Figure 5.1: Example System Configuration

The SRA indenture level consists of:

1. OSC (1.2.1) = Oscillator

2. MPLR (1.2.2) = Multiplier

3. BUFR (1.4.1) = Buffer

The Sub-SRA indenture level consists of:

1. FDBLR (1.2.2.1) = first doubler

2. SDBLR (1.2.2.2.) = second doubler

The driver assembly (1.2) and its lower assemblies will be used to illustrate the LOR analysis since this assembly has SRAs at all indenture levels. Using the LOR code assignment procedure discussed in Chapter IV (Figure 4.2), Figure 5.2 illustrates a few of the possible LOR code assignments for the assemblies (sub-SRAs) and the next highest assemblies (SRAs and WRA).

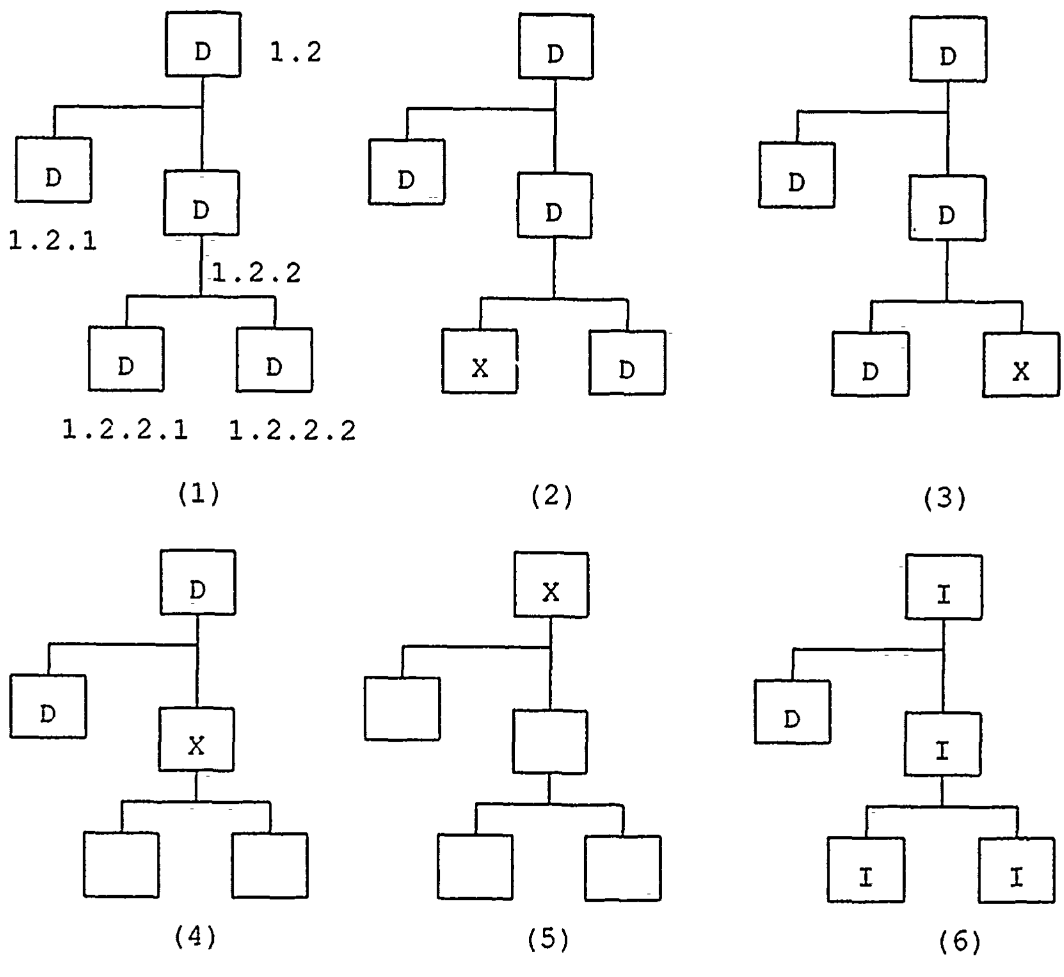

Figure 5.2: LOR Code Assignment Possibilities

The fifty-one possible combinations of LOR code assignments for these five assemblies are listed in Appendix A.

2. Input Data Requirement

A variety of data must be prepared to describe the hardware system being analyzed, the number of sites, number of systems per site, number of assembly types per system, life-cycle length, MTBF, cost factors, turn-around times (TAT) for intermediate and depot repair alternatives, man-hours per action, hourly labor rates, discard rates, etc.

Many of the data elements are represented by a discrete quantitative value or a range of values with an associated probability distribution. The accuracy and completeness of the data depend not only on the sources of data available, but also on the personal experience and motivation of the analyst. The analyst should also possess the right background (e.g., some understanding of system operations and maintenance, mission requirements, and correlation of predicted results with operational experience [Ref. 10:p. 159].).

Following are data that will be used in this example. They are presented by cost category:

1. Manpower

HRD	$ 60.00 per hour
HRI	$ 20.00 per hour
HRO	$ 5.00 per hour
MHRD	3 hours per action
MHRI	5 hours per action
TSI	0.80 hours per action
MHRO = TSO	0.50 hours per action

2. Inventory

DCRD	7%
DCRI	10%
TAT	1,332 hours at the depot level
	888 hours at the intermediate level
	444 hours at the organizational level.
BCMI	2%

3. Repair Material

CF 25%
DCRD, DCRI, BCMI, and other common data same as above.

4. Support equipment

CSEI	\$300,000
CSED	\$225,000
CSEO	\$ 10,000
PCi	3%
PCd	2%
PCo	1%

5. Transportation

WAS	0.50 pound (sub-SRA)
	1.00 pound (SRA)
	3.00 pounds (WRA)
CPD	\$4.00
CPI	\$2.00
CPM	\$3.00

6. Training

DHPD	70% × 8 hours = 5.6 hours
EDPY	300 days
CPT	$5,000
ATR	3%

7. Discount factor

$$y = 15 \text{ years at } i = 10\%:$$

$$DF = \frac{1 + 0.1)^{15} - 1}{0.1(1 + 0.1)^{15}} = 7.6$$

8. Annual Failure

$$ANF = \frac{N \times F \times 365}{MTBF} = \frac{N \times 24 \times 365}{MTBF} = \frac{8760N}{MTBF}$$

The values of N and $MTBF$ are:

$$\begin{aligned}
N &= \text{160 for each assembly.} \\
MTBF &= \text{5000 hours} = MTBF_1 \text{ (WRA 1.2);} \\
&= \text{15000 hours} = MTBF_2 \text{ (SRA 1.2.1);} \\
&= \text{7500 hours} = MTBF_3 \text{ (SRA 1.2.2);} \\
&= \text{12000 hours} = MTBF_4 \text{ (Sub-SRA 1.2.2.1);} \\
&= \text{20000 hours} = MTBF_5 \text{ (Sub-SRA 1.2.2.2).}
\end{aligned}$$

The relationship between these $MTBF$ values are [Ref. 10:Ch. 2 and 5]:

$$1/MTBF_1 = 1/MTBF_2 + 1/MTBF_3$$

or

$$1/5,000 = 1/15,000 + 1/7,500;$$

$$1/MTBF_3 = 1/MTBF_4 + 1/MTBF_5$$

or

$$1/7,500 = 1/12,000 + 1/20,000.$$

9. The unit costs are:

Unit cost (UC) of a WRA	=	\$600.00
Unit cost (UC) of an SRA	=	\$300.00
Unit cost (UC) of a sub-SRA	=	\$150.00

B. LIFE-SUPPORT COST COMPUTATION

Based on the equations developed in Chapter IV, the life-support costs are computed for each category. The first step is to compute the values of Ncd, Nci, and Nco that will be used in the cost equation.

The next step is to compute the total cost of each assembly for each maintenance alternative. With these results, the total costs for each alternative in Appendix A can be computed.

Using the formula in Chapter IV, the values of Ncd, Nci, and Nco can be computed for the specified values of N and $MTBF$. For N=160 and $MTBF$=20,000 hours and depot level repair (TAT=1,332 hours),

$$K = N \times TAT/MTBF = 160 \times 1,332/20,000 = 10.656 \text{ failures}$$

Therefore, the probability of x sub-SRAs failing is:

$$p(x) = \frac{(10.656)^x e^{-10.656}}{x!}$$

We will assume that the protection level required is 0.95; therefore, we want the smallest value of Ncd such that $P(x \leq Ncd) \geq 0.95$. From Table 5.1 we see that the value of Ncd is 16.

Similarly, for the specified values of N and $MTBF$, the values of Ncd, Nci, and Nco are computed and the results are listed in Tables 5.2.

TABLE 5.1: Poisson Probability Distribution for Computing Ncd

x	$p(x)$	$\sum_{x=0}^{Ncd} p(x) = P(x \leq Ncd)$
0	0.000024	0.000024
1	0.000251	0.000275
2	0.001338	0.001612
3	0.004751	0.006363
4	0.012657	0.019020
5	0.026974	0.045994
6	0.047906	0.093900
7	0.072927	0.166827
8	0.097138	0.263965
9	0.115012	0.378977
10	0.122557	0.501534
11	0.118724	0.620258
12	0.105427	0.725685
13	0.086418	0.812103
14	0.065776	0.877879
15	0.046727	0.924606
$\Leftarrow$ 16	0.031120	0.955727

TABLE 5.2: Values of Ncd, Nci, and Nco

N = 160						
TAT (hours)	MTBF (hours)	5,000	7,500	12,000	15,000	20,000
13,320	$Ncd =$	45	37	25	21	16
888	$Nci =$	37	26	18	15	12
444	$Nco =$	19	15	10	9	7

Based on the cost equations developed in Chapter IV, the present value of the various total costs for each alternative can be written for general UC, Ncd, Nci, Nco, WAS, and $MTBF$.

1. Discard Alternative

$$
\begin{aligned}
MPCO &= 8760 \times \frac{N}{MTBF} \times 0.5 \times 5 \times 7.6 \\
&= \$166,440\frac{N}{MTBF} \\
INVCO &= (Nco + 8760 \times \frac{N}{MTBF} \times 7.6) \times UC \\
&= (Nco + 66,576\frac{N}{MTBF}) \times UC \\
SECO &= 10,000 \times (1 + 0.01 \times 7.6) \\
&= \$10,760 \\
TRNCO &= \left[8760 \times \frac{N}{MTBF} \times 0.5/(5.6 \times 300)\right](1 + 0.03 \times 7.6) \times 5,000 \\
&= \$16,004.52\frac{N}{MTBF}
\end{aligned}
$$

Total costs for the discard alternative:

$$
\begin{aligned}
TCO &= \$10,760 + 182,444.52 \times \frac{N}{MTBF} \\
&\quad +(Nco + 66,576 \times \frac{N}{MTBF}) \times UC
\end{aligned}
$$

2. Depot Alternative

$$
\begin{aligned}
MPCD &= 8760 \times \frac{N}{MTBF}(3 \times 60 + 0.8 \times 20 + 0.5 \times 50) \times 7.6 \\
&= \$13,215,336\frac{N}{MTBF}
\end{aligned}
$$

$$
\begin{aligned}
INVCD &= (Ncd + 8760 \times \frac{N}{MTBF} \times 0.07 \times 7.6) \times UC \\
&= (Ncd + 4,660.32\frac{N}{MTBF}) \times UC \\
RMCD &= \left[Ncd + 8760\frac{N}{MTBF}(1 - 0.07) \times 7.6\right] \times 0.25 \times UC \\
&= (0.25Ncd + 15,478.92\frac{N}{MTBF}) \times UC \\
SECD &= 10,760 + 225,000 \times (1 + 0.02 \times 7.6) \\
&= \$269,960 \\
TRPCD &= 8760 \times \frac{N}{MTBF} \times WAS \times 7.6 \times 4.00 \\
&= \$266,304 \times WAS \times \frac{N}{MTBF}
\end{aligned}
$$

Total costs for the depot alternative:

$$
\begin{aligned}
TCD &= \$269,960 + 13,215,336 \times \frac{N}{MTBF} + 266,304 \times WAS \times \frac{N}{MTBF} \\
&\quad +(1.25 \times Ncd + 20,139.24\frac{N}{MTBF}) \times UC
\end{aligned}
$$

3. Intermediate Alternative

$$
\begin{aligned}
MPCI &= 8760 \times \frac{N}{MTBF}[5(1 - 0.02) \times 20 + 3(0.02)60 + 0.5 \times 5] \times 7.6 \\
&= \$6,930,561.6\frac{N}{MTBF} \\
INVCI &= \left[Nci + 8760 \times \frac{N}{MTBF}(0.1 + 0.02) \times 7.6\right] \times UC \\
&= (Nci + 7,989.12\frac{N}{MTBF}) \times UC \\
RMCI &= \left[Nci + 8760 \times \frac{N}{MTBF}\{1 - (0.1 + 0.02)\} \times 7.6\right] \times 0.25 \times UC \\
&= (0.25Nci + 14,646.72\frac{N}{MTBF}) \times UC
\end{aligned}
$$

$$
\begin{aligned}
SECI &= 10,760 + 300,000 \times (1 + 0.03 \times 7.6) \\
&= \$379,160 \\
TRPCI &= 8760 \times \frac{N}{MTBF}(2.00 + 0.02 \times 3.00) \times WAS \times 7.6 \\
&= \$137,146.56 \times WAS \times \frac{N}{MTBF} \\
TRNCI &= \left[8760 \times \frac{N}{MTBF} \times 5/(5.6 \times 300)\right](1 + 0.03 \times 7.6) \times 5,000 \\
&= \$160,080.24 \times \frac{N}{MTBF}
\end{aligned}
$$

Total costs for the intermediate alternative:

$$
\begin{aligned}
TCI = {} & \$379,160 + 7,090,641.84 \times \frac{N}{MTBF} + 137,146.56 \times WAS \\
& \times \frac{N}{MTBF} + (1.25Nci + 22,635.84 \times \frac{N}{MTBF}) \times UC
\end{aligned}
$$

For the $MTBF$ and UC values shown on page 70 and an $N = 160$ the present value of the total costs of each assembly for each maintenance level can be computed (The Ncd, Nci, and Nco values are obtained from Table 5.2).

4. Total Cost for Assembly 1.2 (WRA)

$$
\begin{aligned}
TCD &= 269,960 + 13,215,336 \times 160/5000 + 266,304 \times 3.00 \times 160/5000 \\
&\quad +(1.25 \times 45 + 20,139.24 \times 160/5000) \times 600 \\
&= \$1,138,839.74 \\
TCI &= 379,160 + 7,090,641.84 \times 160/5000 + 137,146.56 \times 3.00 \times 160/5000 \\
&\quad +(1.25 \times 37 + 22,635.84 \times 160/5000) \times 600 \\
&= \$1,081,584.74 \\
TCO &= 10,760 + 182,444.52 \times 160/5000 + (19 + 66,576 \times 160/5000) \times 600 \\
&= \$1,306,257.42
\end{aligned}
$$

5. Total Cost for Assembly 1.2.1 (SRA)

$$
\begin{aligned}
TCD &= 269,960 + 13,215,336 \times 160/15000 + 226,304 \times 1.00 \times 160/15000 \\
&\quad +(1.25 \times 21 + 20,139.24 \times 160/15000) \times 300 \\
&= \$486,084.73 \\
TCI &= 379,160 + 7,090,641.84 \times 160/15000 + 137,146.56 \times 1.00 \times 160/15000 \\
&\quad +(1.25 \times 15 + 22,635.84 \times 160/15000) \times 300 \\
&= \$534,316.10 \\
TCO &= 10,760 + 182,444.52 \times 160/15000 + (9 + 66,570 \times 160/15000) \times 300 \\
&= \$228,449.27
\end{aligned}
$$

6. Total Cost for Assembly 1.2.2

$$
\begin{aligned}
TCD &= 269,960 + 13,215,336 \times 160/7500 + 226,304 \times 1.00 \times 160/7500 \\
&\quad +(1.25 \times 37 + 20,139 \times 160/7500) \times 300 \\
&= \$700,334.46 \\
TCI &= 379,160 + 7,090,641.84 \times 160/7500 + 137,146.56 \times 1.00 \times 160/7500 \\
&\quad +(1.25 \times 26 + 22,635.84 \times 160/7500) \times 300 \\
&= \$687,972.20 \\
TCO &= 10,760 + 182,444.52 \times 160/7500 + (15 + 66,576 \times 160/7500) \times 300 \\
&= \$445,238.55
\end{aligned}
$$

7. Total Cost for Assembly 1.2.2.1

$$
\begin{aligned}
TCD &= 269,960 + 13,215,336 \times 160/12,000 + 226,304 \times 0.50 \times 160/12,000 \\
&\quad +(1.25 \times 25 + 20,139.24 \times 160/12,000) \times 150 \\
&= \$492,905.82 \\
TCI &= 379,160 + 7,090,641.84 \times 160/12,000 + 137,146.56 \times 0.50 \times 160/12,000 \\
&\quad +(1.25 \times 18 + 22,635.84 \times 160/12000) \times 150 \\
&= \$523,262.88 \\
TCO &= 10,760 + 182,444.52 \times 160/12,000 + (10 + 66,576 \times 160/12,000) \times 150 \\
&= \$147,844.59
\end{aligned}
$$

8. Total Cost for Assembly 1.2.2.2

$$
\begin{aligned}
TCD &= 269,960 + 13,215.336 \times 160/20,000 + 226,304 \times 0.50 \times 160/20,000 \\
&\quad +(1.25 \times 16 + 20,139.24 \times 160/20,000) \times 150 \\
&= \$403,914.99
\end{aligned}
$$

$$
\begin{aligned}
TCI &= 379,160 + 7,090,641.84 \times 160/20,000 + 137,146.56 \times 0.50 \times 160/20,000 \\
&\quad + (1.25 \times 12 + 22,635.84 \times 160/20,000) \times 150 \\
&= \$465,846.73 \\
TCO &= 10,760 + 182,444.52 \times 160/20,000 + (7 + 66,576 \times 160/20,000) \times 150 \\
&= \$93,160.76
\end{aligned}
$$

Based on the Appendix A alternatives, the present value of the total life cycle costs associated with each *LOR* code assignment are computed and are presented in Appendix B. In Appendix B the lowest total life-cycle maintenance cost is $1,996,279 for alternative number 37. Therefore, the LOR assignments for the Driver assemblies should be:

- Assembly 1.2: intermediate maintenance level (I)
- Assembly 1.2.1: discard (X)
- Assembly 1.2.2: discard (X)
- Assembly 1.2.2.1: discard (X)
- Assembly 1.2.2.2: discard (X)

How close are other alternatives? For example, consider a complete discard alternative (number 5) with total costs of $2,220,951. This cost is 11% higher than the optimal alternative (number 37). Thus, if the complete discard alternative were chosen, it would be definitely more costly. Consider the next alternative number 23, repair at the depot level of the WRA, and discard of the SRAs and sub-SRAs. The total costs of this alternative are $2,053,533, only 2.8% higher than the optimal alternative. This alternative might be worth choosing instead of the optimal alternative, especially if the number of maintenance personnel at the intermediate level is not adequate. In

addition, the maintenance personnel at the intermediate level could perhaps be shifted to other activities since repair of the WRA is performed by the contractor. Thus, a cost saving could result which was not actually part of the *LOR* model. This near optimal solution presented to a decision maker allows him to incorporate his knowledge about other aspects of the problem in making a final decision.

VI. SUMMARY, CONCLUSIONS, and RECOMMENDATIONS

A. SUMMARY

This thesis develops the level of repair (LOR) analysis model for the case where weapon systems have already been designed by some other country and are being used by the Indonesian Navy. This model incorporates the existing maintenance levels of the Indonesian Navy and allows for weapon system indenture levels. Using this model, the present value of the total life-cycle costs for each indenture level and its maintenance level alternative can be computed. From summing these total life-cycle costs for each alternative, the optimal LOR assignment can be determined for each indenture level.

B. CONCLUSIONS

1. The most important factors in the procurement decision process are life-cycle costs (LCC), system effectiveness and the equipment being considered. The life-support costs (LSC) are a significant part of LCC, especially for the navies of developing countries which usually buy weapon systems that have already been designed and produced by the industrial country. The model developed in this thesis allows LOR analysis for any developed system that the Indonesian Navy wishes to buy.

2. The framework of the LOR analysis presented in this thesis can be applied in the Indonesian Navy because it was purposely designed to consider the current maintenance levels of the Indonesian Navy.

3. The Indonesian Navy plans to become involved in system design development at its national shipyard as a consequence a program of frigate building based on licensing agreements from various industrial countries. Involvement in system design during the weapon systems acquisition process would be a major step toward increasing the Indonesian Navy's logistics planning capability, but a more elaborate LOR model will be needed when this occurs.

4. There are some potential constraints in the short run. Obtaining access to reliability and maintainability data for the weapon system being purchased may be difficult. Maintainability and material support data may also difficult to access. The model may be incomplete when application is attempted. Computer programming of the model will be necessary and may take considerable time.

C. RECOMMENDATIONS

The LOR model proposed in this thesis should be used by the Indonesian Navy as a first step in evaluating the life-cycle support costs for weapon systems purchased from other countries and should be the best method for maintaining such systems. In addition to those constraints mentioned in Conclusion 4 above, several other important aspects must be considered before the model can be used. These include: the level of protection desired for spares and repair parts, how to determine the new system's maintenance parameters (MTBF, required maintenance hours, indenture levels, etc.) after the Indonesian Navy buys the system, transportation times and costs between organizational, intermediate, and depot levels, expected discard rates at the intermediate and depot levels, and repair material and support equipment cost factors. Because of the size of the effort to implement this model, a project team needs to be formed. Such a team should include cost analysts, operations

analysts, and computer scientists, as well as experts from the current supply and maintenance organizations.

APPENDIX A

The Possible Alternatives of LOR Assignment

	Assemblies				
	WRA	SRA	Sub-SRA		
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2
(1)	(2)	(3)	(4)	(5)	(6)
1	D	D	D	D	D
2	D	D	D	X	D
3	D	D	D	D	X
4	D	D	X	–	–
5	X	–	–	–	–
6	I	D	I	I	I
7	I	D	I	D	D
8	I	D	I	I	D
9	I	D	I	D	I
10	I	D	I	I	X
11	I	D	I	X	I
12	I	D	I	D	X
13	I	D	I	X	D
14	I	D	I	X	X
15	I	D	D	D	D
16	I	D	D	D	X
17	I	D	D	X	D
18	I	D	D	X	X
19	I	D	X	–	–
20	D	X	D	D	D
21	D	X	D	X	D
22	D	X	D	D	X
23	D	X	X	–	–
24	I	X	I	I	I
25	I	X	I	D	D
26	I	X	I	I	D
27	I	X	I	D	I
28	I	X	I	I	X
29	I	X	I	X	I

	Assemblies				
	WRA	SRA	Sub-SRA		
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2
(1)	(2)	(3)	(4)	(5)	(6)
30	I	X	I	D	X
31	I	X	I	X	D
32	I	X	I	X	X
33	I	X	D	D	D
34	I	X	D	D	X
35	I	X	D	X	D
36	I	X	D	X	X
37	I	X	X	–	–
38	I	I	I	I	I
39	I	I	I	D	D
40	I	I	I	I	D
41	I	I	I	D	I
42	I	I	I	I	X
43	I	I	I	X	I
44	I	I	I	D	X
45	I	I	I	X	D
46	I	I	I	X	X
47	I	I	D	D	D
48	I	I	D	D	X
49	I	I	D	X	D
50	I	I	D	X	X
51	I	I	X	–	–

APPENDIX B

Total Life Cycle Costs for the LOR Alternatives for the Driver Assemblies

	Assemblies					
	WRA	SRA	Sub-SRA			
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2	Sum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	D	D	D	D	D	
	1,138,839	486,085	700,334	492,906	403,915	3,222,079
2	D	D	D	X	D	
	1,138.839	486,085	700,334	147,845	403,915	2,877,018
3	D	D	D	D	X	
	1,138,839	486,085	700,334	492,906	93,161	2,911,325
4	D	D	X	–	–	
	1,138,839	486,085	445,239	147,845	93,161	2,311,169
5	X	–	–	–	–	
	1,306,257	228,449	445,239	147,845	93,161	2,220,951
6	I	D	I	I	I	
	1,081,585	486,085	687,972	523,263	465,847	3,244,752
7	I	D	I	D	D	
	1,081,585	486,085	687,972	492,906	403,915	3,152,463
8	I	D	I	I	D	
	1,081,585	486,085	687,972	523,263	403,915	3,182,820
9	I	D	I	D	I	
	1,081,585	486,085	687,972	492,906	465,847	3,214,395
10	I	D	I	I	X	
	1,081,585	486,085	687,972	523,263	93,161	2,872,066
11	I	D	I	X	I	
	1,081,585	486,085	687,972	147,845	465,847	2,869,333
12	I	D	I	D	X	
	1,081,585	486,085	687,972	492,906	93,161	2,841,709

	Assemblies					
	WRA	SRA	Sub-SRA			
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2	Sum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
13	I	D	I	X	D	
	1,081,585	486,085	687,972	147,845	403,915	2,807,402
14	I	D	I	X	X	
	1,081,585	486,085	687,972	[illegible]	93,161	2,496,648
15	I	D	D	D	D	
	1,081,585	486,085	700,334	492,906	403,915	3,164.825
16	I	D	D	D	X	
	1,081,585	486,085	700,334	492,906	93,161	2,854,071
17	I	D	D	X	D	
	1,081,585	486,085	700,334	147,845	403,915	2,819,764
18	I	D	D	X	X	
	1,081,585	486,085	700,334	147,845	93,161	2,509,010
19	I	D	X	–	–	
	1,081,585	486,085	445,239	147,845	93,161	2,253,915
20	D	X	D	D	D	
	1,138,839	228,449	700,334	492,906	403,915	2,964,443
21	D	X	D	X	D	
	1,138,839	228,449	700,334	147,845	403,915	2,619,382
22	D	X	D	D	X	
	1,138,839	228,449	700,334	492,906	93,161	2,653,689
23	D	X	X	–	–	
	1,138,839	228,449	445,239	147,845	93,161	2,053,533
24	I	X	I	I	I	
	1,081,585	228,449	687,972	523,263	465,847	2,987,116

	Assemblies					
	WRA	SRA	Sub-SRA			
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2	Sum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
25	I	X	I	D	D	
	1,081,585	228,449	687,972	492,906	403,915	2,894,827
26	I	X	I	I	D	
	1,081,585	228,449	687,972	523,263	403,915	2,925,184
27	I	X	I	D	I	
	1,081,585	228,449	687,972	492,906	465,847	2,956,759
28	I	X	I	I	X	
	1,081,585	228,449	687,972	523,263	93,161	2,614,430
29	I	X	I	X	I	
	1,081,585	228,449	687,972	147,845	465,847	2,611,698
30	I	X	I	D	X	
	1,081,585	228,449	687,972	492,906	93,161	2,584,073
31	I	X	I	X	D	
	1,081,585	228,449	687,972	147,845	403,915	2,549,766
32	I	X	I	X	X	
	1,081,585	228,449	687,972	147,845	93,161	2,239,012
33	I	X	D	D	D	
	1,081,585	228,449	700,334	492,906	403,915	2,907,189
34	I	X	D	D	X	
	1,081,585	228,449	700,334	492,906	93,161	2,596,435
35	I	X	D	X	D	
	1,081,585	228,449	700,334	147,845	403,915	2,562,128
36	I	X	D	X	X	
	1,081,585	228,449	700,334	147,845	93,161	2,251.374

	Assemblies					
	WRA	SRA	Sub-SRA			
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2	Sum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
37	I	X	X	–	–	
	1,081,585	228,449	445,239	147,845	93,161	1,996,279
38	I	I	I	I	I	
	1,081,585	534,316	687,972	523,263	465,847	3,292,983
39	I	I	I	D	D	
	1,081,585	534,316	687,972	492,906	403,915	3,200,694
40	I	I	I	I	D	
	1,081,585	534,316	687,972	523,263	403,915	3,231.051
41	I	I	I	D	I	
	1,081,585	534,316	687,972	492,906	465,847	3,262,626
42	I	I	I	I	X	
	1,081,585	534,316	687,972	523,262	93,161	2,921,296
43	I	I	I	X	I	
	1,081,585	534,316	687,972	147,845	465,847	2,917,565
44	I	I	I	D	X	
	1,081,585	534,316	687,972	492,906	93,161	2,889,940
45	I	I	I	X	D	
	1,081,585	534,316	687,972	147,845	403,915	2,855,633
46	I	I	I	X	X	
	1,081,585	534,316	687,972	147,845	93,161	2,544,879
47	I	I	D	D	D	
	1,081,585	534,316	700,334	492,906	403,915	3,213,056
48	I	I	D	D	X	
	1,081,585	534,341	700,334	492,906	93,161	2,902,327

	Assemblies					
	WRA	SRA	Sub-SRA			
Alternative	1.2	1.2.1	1.2.2	1.2.2.1	1.2.2.2	Sum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
49	I	I	D	X	D	
	1,081,585	534,316	700,334	147,845	403,915	2,867,995
50	I	I	D	X	X	
	1,081,585	534,316	700,334	147,845	93,161	2,557,241
51	I	I	X	–	–	
	1,081,585	534,316	445,239	147,845	93,161	2,302,146

APPENDIX C

A Glossary of Abbreviations and Acronyms

AASS	=	Average annual system stock quantity
ADT	=	Administrative delay time
ADHR	=	Annual duty hours per person
ANF	=	Average annual failures of an item
ATR	=	Personnel attrition rate
BCM	=	Beyond capability of maintenance rate
BCMI	=	BCM rate at the intermediate level
BUFR	=	Buffer assembly
CF	=	Cost factor as a percentage of the unit cost of module
CP	=	Shipping cost per pound
CPT	=	Training cost per person
CSE	=	Initial cost of support equipment
D	=	Depot level
DF	=	Discount factor
DCR	=	Discard rate
DHPD	=	Duty hours per person per day
DRIV	=	Driver assembly
EDPY	=	Effective repair days per year
F	=	Average operating hours per module per day

FDBLR	=	First doubler assembly
HR	=	Hourly labor rate
I	=	Intermediate level
ILS	=	Integrated logistic support
INVC	=	Total life-cycle inventory costs
IRMC	=	Initial repair material costs
ITRNC	=	Initial training costs
LCC	=	Life-cycle cost
LDT	=	Logistic delay time
LSA	=	Logistic support analysis
LSC	=	Life-support cost
LOR	=	Level of repair analysis
M	=	Mean active maintenance time
MDT	=	Maintenance downtime
MHR	=	Manhours per action
MIL-STD	=	Military standard
MOD	=	Modulator assembly
MPLR	=	Multiplier assembly
MTBF	=	Mean time between failures
N	=	Number of application of identical modules in a system multiplied by the number of systems per operational site, and multiplied by the number of operational sites.

Nc	=	Number of spare modules as a protection level during turn around time or inventory resupply time
O	=	Organizational level
OSC	=	Oscillator assembly
PA	=	Power amplifier assembly
PSA	=	Power supply assembly
PC	=	Percentage of the initial support equipment costs
RMC	=	Total life-cycle repair material costs
SDBLR	=	Second doubler assembly
SEC	=	Total life-cycle support equipment costs
SRA	=	Shop replaceable assembly
TAT	=	Turn around time or inventory system resupply time
TRNC	=	Total life-cycle training costs
TRPC	=	Total life-cycle transportation costs
TSI	=	Time spent at intermediate level for each failure
TSO	=	Time spent at organizational level for each failure
UC	=	Unit cost of module
WAS	=	Weight of an assembly in pounds
WRA	=	Weapon replaceable assembly
X	=	Discard at failure

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